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THESIS

AN ANALYSIS ON THE SURVIVABILITY OF
LAND ATTACK MISSILES (LAM)

by

Michael S. Johnston

December 2000

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This thesis develops a process to assist military planners in assessing and evaluating the effectiveness of land attack missiles. The aforementioned process contains the means to address the variety of important issues and concerns that are associated with the employment of such land attack missile systems. The Department of the Navy is proposing a new land attack missile that will be employed by the Destroyer of the 21st Century (DD 21) to assist in performing Naval Surface Fire Support missions for Marines and Army troops operating ashore. This research focuses on using the Extended Air Defense Simulation (EADSIM) to estimate the probability of LAM survival for different variants of land attack missiles against various threats. The analysis concludes that the most survivable cruise missile variants have an altitude of at least 4,000 meters, speed of at least 1,610 knots, and stealthy enough to limit the enemy air defense site detection range to 1% of its maximum range. Survivable ballistic missile variants have a lofted trajectory, speed in the 2,577 knot range, and stealthy enough to limit the enemy air defense site detection range to 10% of its maximum range. The data in this thesis is from unclassified sources, but the process can be applied with classified numerical parameters.

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AN ANALYSIS ON THE SURVIVABILITY OF LAND ATTACK MISSILES (LAM)

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ABSTRACT

This thesis develops a process to assist military planners in assessing and evaluating the effectiveness of land attack missiles. The aforementioned process contains the means to address the variety of important issues and concerns that are associated with the employment of such land attack missile systems. The Department of the Navy is proposing a new land attack missile that will be employed by the Destroyer of the 21st Century (DD 21) to assist in performing Naval Surface Fire Support missions for Marines and Army troops operating ashore. This research focuses on using the Extended Air Defense Simulation (EADSIM) to estimate the probability of LAM survival for different variants of land attack missiles against various threats. The analysis concludes that the most survivable cruise missile variants have an altitude of at least 4,000 meters, speed of at least 1,610 knots, and stealthy enough to limit the enemy air defense site detection range to 1% of its maximum range. Survivable ballistic missile variants have a lofted trajectory, speed in the 2,577 knot range, and stealthy enough to limit the enemy air defense site detection range to 10% of its maximum range. The data in this thesis is from unclassified sources, but the process can be applied with classified numerical parameters.

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LIST OF SYMBOLS, ACRONYMS AND/OR ABBREVIATIONS

AGL	Above Ground Level
AGS	Advanced Gun System
ALAM	Advanced Land Attack Missile
ATACMS	Army Tactical Missile System
BAT	Brilliant Anti-Tank
BMDO	Ballistic Missile Defense Organization
DD 21	Destroyer of the 21st Century
DoD	Department of Defense
DPICM	Dual Purpose Improved Conventional Munition
DTED	Detailed Terrain and Elevation Data
EADSIM	Extended Air Defense Simulation
ERGM	Extended Range Gun Munition
IQR	Interquartile Range
IR	Infrared
LAM	Land Attack Missile
LASM	Land Attack Standard Missile
MANPADS	Manned Portable Air Defense System
MOE	Measure of Effectiveness
MOP	Measure of Performance
MSE	Mean Squared Error
MSL	Mean Sea Level
NSFS	Naval Surface Fire Support
ORD	Operational Requirements Document
P_e	Probability of Engagement
P_k	Probability of Kill
RCS	Radar Cross Section
SAM	Surface-to-Air Missile
SDC	Strategic Defense Command
SE	Standard Error
SEAD	Suppression of Enemy Air Defenses
SM-2	Standard Missile 2
SSE	Sum Squared Error
STOM	*Ship to Objective Maneuver*
TACTOM	Tactical Tomahawk
THAAD	Theater High Altitude Area Defense
VLS	Vertical Launching System

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EXECUTIVE SUMMARY

A new Land Attack Missile (LAM) is currently being considered by the Navy to assist in performing Naval Surface Fire Support missions for Marines and Army troops operating ashore. The LAM is projected to fill a void in the Naval Surface Fire Support between the range of the gun munitions and the Marine Corps' concept of *Ship to Objective Maneuver* (STOM), which calls for fire support for Marine forces taking an objective 200 miles inland.

The LAM will have improved lethality and an expanded target set, which will allow it to strike emerging targets to support the ground forces moving ashore. The LAM will optimize its capability from about two hundred to three hundred nautical miles from the ship. The LAM is projected to have the range to kill targets at the limit of the current Ballistic Missile Treaty of 600 km, approximately 330 nm (Start I, 1991).

The purpose of this thesis is to develop a process to assist decision makers in assessing the effectiveness of proposed variants of the Land Attack Missile (LAM). The process will begin by identifying LAM variants, identifying a range of threats, and running the LAM variants through the model, looking for LAM alternatives that are the most survivable across a range of operational scenarios.

A developmental briefing at Johns Hopkins University on the Advanced Land Attack Missile (ALAM) program revealed four initial flight profiles under consideration.

Flight Profile	Air Speed (Mach)
Subsonic Cruise	0.65
Supersonic Cruise	2.3
Ballistic-glide	4
Hypersonic Cruise	5

Table 1. Initial ALAM Flight Profiles

The subsonic cruise flight profile is a terrain following profile with speeds less than Mach 1. Terrain masking is the key to making subsonic cruise missiles effective, like the current Tomahawk cruise missile. Missiles with the supersonic and hypersonic cruise profiles launch from a ship, proceed upward to a specified altitude above mean sea level (MSL), fly along a specified straight path at speeds from about Mach 1 to Mach 5, and descend to the target at approximately a 45 degree dive angle. The ballistic-glide flight profile launches from a ship and is propelled upward to its apogee altitude, based upon the total distance from the ship to the target, then descends using gravity as its source of acceleration.

The aforementioned missile alternatives will be designed to carry both unitary and sub-munitions payloads. Two types of unitary warheads being considered are blast and penetrating. Sub-munitions payloads include anti-personnel, anti-material, (dual purpose improved conventional munition, DPICM) and anti-tank (brilliant anti-tank sensor-fused weapon, BAT) (Mullen, 1999). This thesis focuses on the survivability of the missile variants versus low, medium, and high threat land-based air defenses. A missile is considered successful in this thesis if its survivability is 80%. That is, it gets through the air defense systems and reaches the target at least 80% of the time. The data is presented in terms of P_k, which is 1 – the probability of survival. The DoD validated model, Extended Air Defense Simulation (EADSIM), is used to generate missile survivability data. Nearly 20,000 simulated LAM attacks were used to generate the insights. For all of the scenarios, we assume an alerted threat with a perfect state of readiness for enemy air defense sites.

The low threat scenario is vulnerable to both cruise and ballistic missile LAM variants. As the altitude and speed variables increase, the probability the LAM is killed by an enemy air defense site, P_k, decreases in the cruise missile variants. The most preferred ballistic missile variants in the low threat scenario have a depressed trajectory and a small detection range. As expected, many combinations of cruise and ballistic missiles penetrate the enemy air defenses in the low threat scenario. All the combinations that have P_k values less than or equal to 0.2, i.e., are at least 80% survivable, are listed in Appendices C and D.

In the medium threat scenario the acceptable cruise missile LAM variants fly above 3,000 meters and at least 1,933 knots. As altitude and speed increase, the survivability of the LAM increases for the medium threat level cruise missiles. The ballistic missile variants, like the low threat scenario, are more survivable when the LAM variant has a depressed trajectory and a low detection range.

The high threat scenario presents many problems for cruise and ballistic missile LAMs. A majority of the cruise and ballistic missiles are killed in all the replications. The alerted, modern, integrated air defense is only penetrated by very stealthy cruise missiles with a detection range value of 1% and a speed of at least 1,933 knots, depressed trajectory ballistic missiles with a detection range value less than 10%, or lofted trajectory ballistic missiles.

In the low and medium threat scenario, higher altitudes and faster speeds increase the probability of survival for the LAM variants. In the high threat scenario, only excursion runs with an extremely low detection range of 1% make it through the air defenses.

The ballistic missile LAM variants are successful in the low and medium threat scenarios when the detection range is 50% or lower for depressed trajectories, or when a lofted trajectory is used. The high threat scenario is only defeated when the LAM has a lofted trajectory and a detection range of 10% or lower. Speed is not a factor in the ballistic missile LAMs tested.

The high threat scenario proves to be the most difficult set of air defenses to penetrate. This is not surprising, but does indicate that a sophisticated missile must be used to achieve successful target destruction. The sign test confirms that the threat level of the scenario does make a difference in the success, or failure, of the LAM. The most survivable cruise missile LAM variants have an altitude of at least 4,000 meters, speed of at least 1,610 knots (Mach 2.3), and stealthy enough to limit the enemy air defense site detection range to 1% of its maximum range. Survivable ballistic missile LAM variants have a lofted trajectory, speed in the 2,577 knot (Mach 4.0) range, and stealthy enough to limit the enemy air defense site detection range to 10% of its maximum range.

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I. INTRODUCTION

A. BACKGROUND

Military planners need tools to continually assess and evaluate the effectiveness of future combat systems. These planning tools must contain the means to address the variety of important issues and concerns that are associated with the employment of the systems. One such system being proposed by the Department of the Navy is a new land attack missile that will be employed by the Destroyer of the 21st Century (DD 21). DD 21 is projected to have an initial operating capability in 2010. (Bohmfalk, 2000)

Aside from air power, the Department of Defense (DoD) currently has the Tomahawk missile for use in long-range land attack operations and the Army Tactical Missile System (ATACMS) for shorter-range land attack operations. The ATACMS must be ground-deployed, while the Tomahawk can be fired from a ship.

The Surface Navy currently has several projects underway to enhance its land attack capability to support operations and the Navy and Marine Corps' concepts of *Forward From the Sea* and *Operational Maneuver From the Sea*, respectively. The traditional Naval Gun is being upgraded. The Extended Range Gun Munition (ERGM) is being introduced on newly commissioned Arleigh Burke class destroyers to increase Naval Surface Fire Support (NSFS) to a range of about 60 miles (Seigle, 1999). A more advanced and longer-range system, the Advanced Gun System (AGS), will be incorporated into DD 21. (Dalton, 1994)

Another one of these projects is to create a variant of the current Tomahawk cruise missile, which will be called Tactical Tomahawk (TACTOM). The TACTOM will be a loitering cruise missile that can be given new targeting information while in flight. Yet another project is the Land Attack Standard Missile (LASM), which is the first phase in the Operational Requirements Document (ORD) for a Land Attack Missile (LAM). It will be a low cost alteration to the current Standard Missile 2 (SM-2) and will possess a short-range land attack capability. (Mullen, 1999)

B. OVERVIEW

A new Land Attack Missile (LAM) is currently being considered by the Navy to assist in performing Naval Surface Fire Support missions for Marines and Army troops operating ashore. The LAM is projected to fill a void in the Naval Surface Fire Support between the range of the gun munitions and the Marine Corps' concept of *Ship to Objective Maneuver* (STOM), which calls for fire support for Marine forces taking an objective 200 miles inland.

The LAM will have improved lethality and an expanded target set, which will allow it to strike emerging targets to support the ground forces moving ashore. The LAM will optimize its capability from about two hundred to three hundred nautical miles from the ship. The LAM is projected to have the range to kill targets at the limit of the current Ballistic Missile Treaty of 600 km, approximately 330 nm (Start I, 1991).

C. OBJECTIVE

The purpose of this thesis is to develop a process to assist decision makers in assessing the survivability of proposed variants of the Land Attack Missile (LAM). The process will begin by identifying LAM variants, identifying a range of threats, and running the model across the LAM variants looking for LAM alternatives that are the most survivable across a range of operational scenarios. For this thesis, a successful LAM will have a probability of survival of 80%.

A developmental briefing at Johns Hopkins University on the Advanced Land Attack Missile (ALAM) program revealed four initial flight profiles under consideration.

Flight Profile	Air Speed (Mach)
Subsonic Cruise	0.65
Supersonic Cruise	2.3
Ballistic-glide	4
Hypersonic Cruise	5

Table 2. Initial ALAM Flight Profiles

The subsonic cruise flight profile is a terrain following profile with speeds less than Mach 1. Terrain masking is the key to making subsonic cruise missiles survivable, like the current Tomahawk cruise missile. The supersonic and hypersonic cruise profile missiles launch from a ship, proceed upward to a specified altitude above mean sea level (MSL), fly along a specified straight path at speeds from about Mach 1 to Mach 5, and descend to the target at approximately a 45 degree dive angle. The LAMs with a ballistic-glide flight profile launch from a ship and are propelled upward to their apogee altitude, based upon the total distance from the ship to the target, then descend using gravity as their source of acceleration.

The aforementioned missile alternatives will be designed to carry both unitary and sub-munitions payloads. Two types of unitary warheads being considered are blast and penetrating. Sub-munitions payloads include anti-personnel, anti-material, (dual purpose improved conventional munition, DPICM) and anti-tank (brilliant anti-tank sensor-fused weapon, BAT) (Mullen, 1999). This thesis focuses on the survivability of the missile variants versus low, medium, and high threat land-based air defenses. The DoD validated model, Extended Air Defense Simulation (EADSIM), is used to generate missile survivability data.

D. EADSIM BACKGROUND

According to Mark McAnally, the Chief Engineer of EADSIM at Teledyne Brown Engineering, accreditations by joint and service organizations have been performed, including the Ballistic Missile Defense Organization (BMDO) and the Theater High Altitude Area Defense (THAAD) program. Verification and Validation efforts have been conducted by many organizations, including USSTRATCOM, AFOTEC, JSF, SMART, USASMDC, BMDO, and others. EADSIM has undergone a number of examinations by users and has completed a Level 1 confidence assessment as part of the BMDO Analytic Tool Box. A multi-service assessment has been performed several times and the EADSIM program is ISO 9001 certified. (McAnally, 2000)

EADSIM is a stochastic mission-level simulation model developed by Teledyne Brown Engineering and is currently managed by the U.S. Army Strategic Defense Command (SDC) in Huntsville, Alabama. Many detailed inputs, such as radar frequencies, missile probabilities of kill, and reaction times, are used to determine the outcome of each scenario. EADSIM is ideally suited for a detailed in-depth study of a raid on integrated air defenses and was used to extensively model DESERT SHIELD and DESERT STORM. (Case, 1995)

E. RESEARCH

1. Phase One

The research is divided into two phases. Phase one consists of building the simulation in EADSIM. Unclassified data for the enemy air defenses is entered and enemy systems are created. These systems are then deployed in an enemy laydown configuration in EADSIM using generic enemy defensive strategies. The subsonic, supersonic, and hypersonic cruise LAMs are launched from a simulated DD 21 approximately 20 miles offshore. These LAM variants have preplanned waypoints and routes similar to those of the current Tomahawk cruise missile, except these routes force the LAM to fly directly through the strength of the enemy air defenses with minimal terrain masking. This ensures the data is from a "worst case" scenario. That is, we expect better results, i.e., higher survivability, in actual conditions.

The ballistic-glide LAMs are also launched from the same simulated DD 21 offshore and follow either a depressed trajectory flight path or a lofted trajectory flight path. The depressed trajectory flight path ensures the LAM variants do not exceed current realistic apogee altitudes on their path to the target. There is much debate between the services on how to deconflict a missile flying through high altitude airspace, so the lofted trajectory may not be a feasible option. The lofted trajectory flight path is included in order to obtain possible results. The lofted trajectory allows the missile to have approximately an 80-degree dive angle on the target, whereas the depressed trajectory has a dive angle between 20 – 25 degrees. Once again, the flight paths are routed through the teeth of the enemy air defenses (CNA, 1992).

2. Phase Two

Phase two consists of parametrically varying key factors and analyzing the statistical results of the different LAM variants run through the scenarios. This includes statistical hypothesis tests to determine if differences are statistically significant. The objective is to find the LAM variant that has the highest survivability against each and/or all of the enemy air defenses. The Measure of Effectiveness (MOE) is the probability the LAM survives to its intended target. It is measured statistically with P_k, where k is killed by an enemy air defense site. If the LAM is 80% survivable, it has a P_k value of 0.2. A lower MOE value represents a more effective LAM variant since the goal is to maximize survivability and minimize enemy air defense site lethality. The Measure of Performance (MOP) is the probability the LAM is engaged (P_e) by an enemy air defense site. S-Plus 2000 and Microsoft Excel are the data analysis tools used in the parametric analysis of the data (MathSoft, 1999).

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II. METHODS

A. RESEARCH

Different threat levels of air defense systems and variations of the LAM are simulated using the Extended Air Defense Simulation (EADSIM). There are three different threat levels of enemy air defenses: low, medium, and high. Each level of enemy air defense is completely independent from the others and referred to as a scenario in EADSIM. Each scenario consists of a friendly (blue) laydown, an enemy (red) laydown, and an associated Detailed Terrain and Elevation Data (DTED) image of the terrain. Laydown refers to the specific layout of the systems in the scenario, whether they are complex, like an air defense site, or simple, like a target area. In EADSIM, different laydowns can be placed on top of the terrain to make a complete picture of all the systems in the scenario.

Every ship, cruise missile, ballistic missile, enemy air defense site, and target has to be created in EADSIM, in order to be used in any scenario. Each ship, cruise missile, and enemy air defense site is considered a system in EADSIM. The individual systems consist of their own sensors, rule sets, and weapons. So, for instance, each enemy air defense site type, whether it is an anti-aircraft gun, surface-to-air missile launcher, or a combination of both, must have at least one sensor, rule set, and weapon entered and saved. Eleven different enemy air defense site systems were created for this thesis. The ballistic missiles are considered weapons in EADSIM and the targets are placed in the scenario at an arbitrary position from the DD 21. (Teledyne Brown, 1998)

Only scenarios involving a single missile, whether it is a ballistic or a cruise missile, are run. No suppression of enemy air defenses (SEAD) by friendly aircraft or special operations teams is taken into account. The cruise missiles use only four waypoints en route to the target. This minimizes terrain masking and known air defense site avoidance procedures, which are necessary for subsonic missiles to survive. The ballistic missiles are difficult to model explicitly and change dramatically in apogee altitude as the range between the launching platform and the target is increased or decreased.

B. LAYDOWNS

1. Friendly

The friendly (blue) laydown consists of a blue destroyer ship icon that represents a DD 21. The DD 21 is the launching platform for all the cruise and ballistic missile LAMs. The cruise and ballistic missiles are modeled differently in EADSIM, so a separate scenario is built for each. Hence, there are low threat, medium threat, and high threat cruise scenarios, along with low, medium, and high threat ballistic scenarios. The only difference between the blue laydown in the scenarios is the way in which the LAM is modeled.

2. Enemy

The second part of each scenario is the enemy (red) laydown. Each of the three threat levels corresponds to differing levels of enemy air defenses, to include such things as defense in depth, and overlapping sensor coverage. The idea is that the LAM would be a missile used against various threats without modifying the missile, other than possibly the warhead, between applications. Each of the laydowns is very different depending on whether it is the low, medium, or high enemy threat.

C. LOW THREAT

The low threat enemy laydown shown in Figure 1, consists of basic anti-aircraft guns spread out sporadically along the LAM's flight path to the target. The anti-aircraft guns are unclassified versions of some older Russian models that are available to any third world nation for the right price. Each model of anti-aircraft gun is entered into EADSIM by using the appropriate sensors, weapons, rule sets, and systems. The DD 21 in the low scenario is 50 kilometers, 27 nautical miles, offshore. The low threat target is approximately 300 kilometers, 162 nautical miles, from the ship.

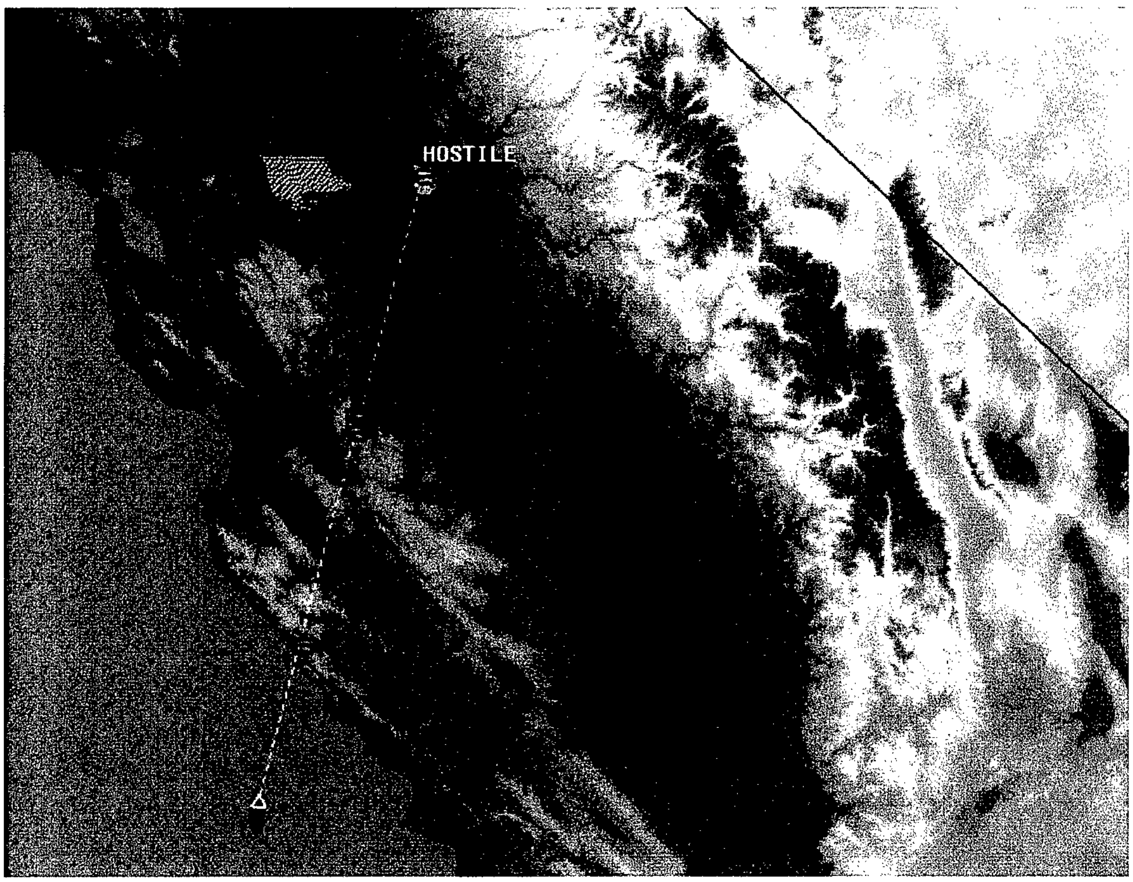

Figure 1. Detailed Terrain Image of the Low Threat Scenario Showing DD 21 Launching Platform, Cruise Missile Flight Path, Enemy Air Defense Sites, and Hostile Target.

Figure 2 shows a closer image of the target area and the air defenses surrounding it. The cruise missile's path is shown with white dashed lines, while the hostile target is represented by the yellow star with the word "HOSTILE" next to it. The enemy air defense sites are depicted in different colors to represent different capabilities of the systems.

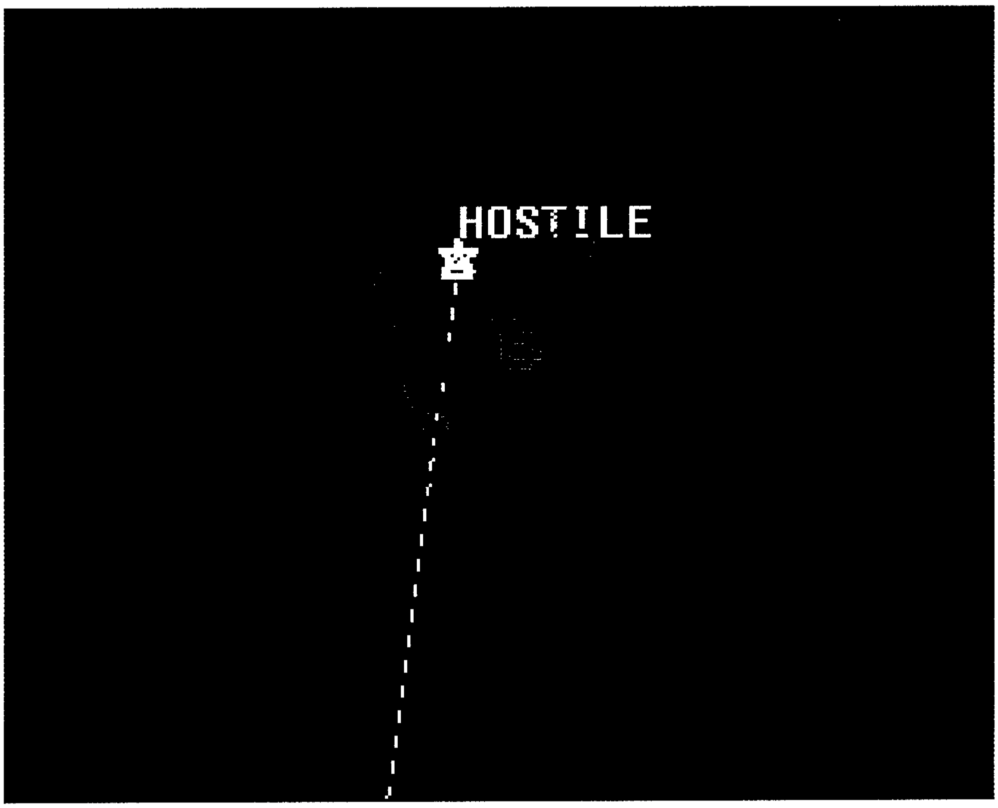

Figure 2. Close-Up Image of the Medium Threat Scenario Showing the Terminal Cruise Missile Flight Path, Enemy Air Defense Sites, and the Hostile Target.

D. MEDIUM THREAT

The medium threat enemy laydown displayed below in Figure 3, features basic anti-aircraft guns, older, less-capable Russian surface-to-air missile (SAM) systems, and hand-held surface-to-air missile launchers, commonly referred to as manned portable air defense systems (MANPADS). The systems are spread out, but grouped to imply some coordination, along the LAM's flight path to the target. The anti-aircraft guns are the same as the ones used in the low threat scenario. The SAMs and MANPADs are unclassified versions of older Russian models that are for sale to any nation. Each model of anti-aircraft gun, surface-to-air missile, or MANPAD was entered into EADSIM by using the appropriate sensors, weapons, rule sets, and systems described previously. The DD 21 in the medium scenario is 80 kilometers, 43 nautical miles, offshore. The medium threat target is approximately 270 kilometers, 148 nautical miles, from the ship.

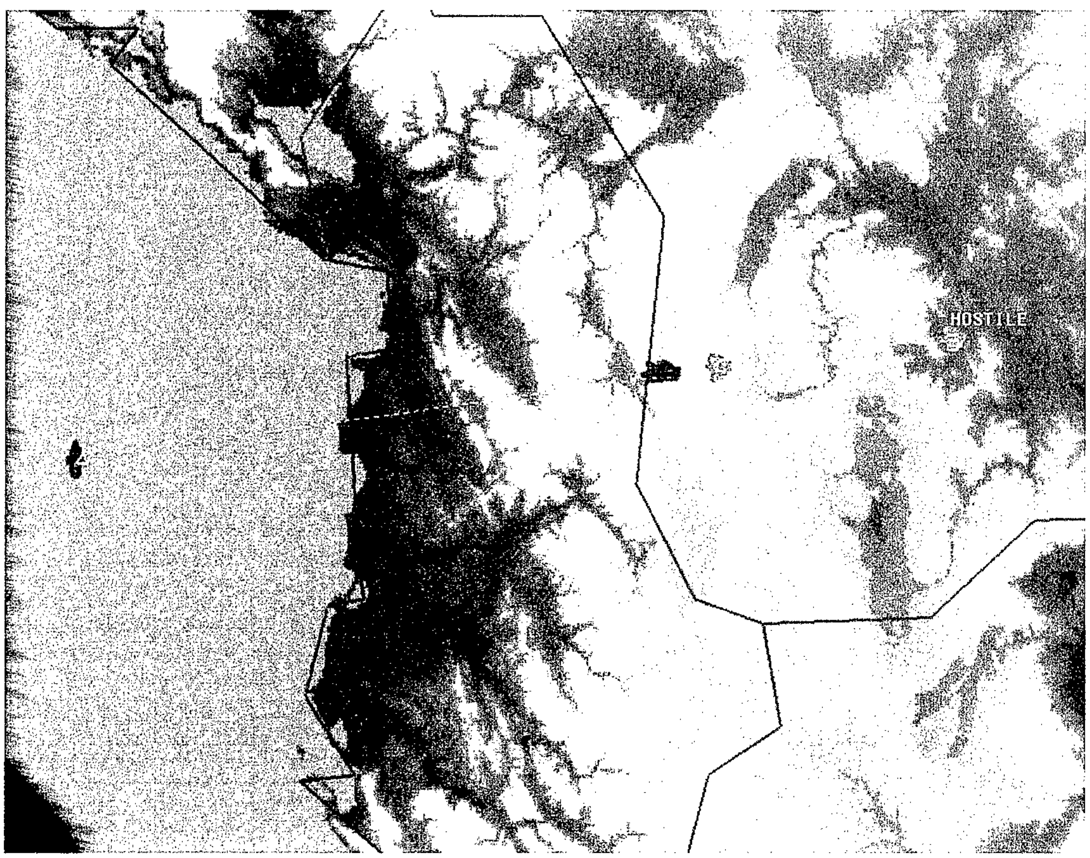

Figure 3. Detailed Terrain Image of the Medium Threat Scenario Showing DD 21 Launching Platform, Cruise Missile Flight Path, Enemy Air Defense Sites, and Hostile Target.

Figure 4 shows the target area and its surrounding air defense sites. The cruise missile enters from the left part of the figure and proceeds to the hostile target unless it is shot down.

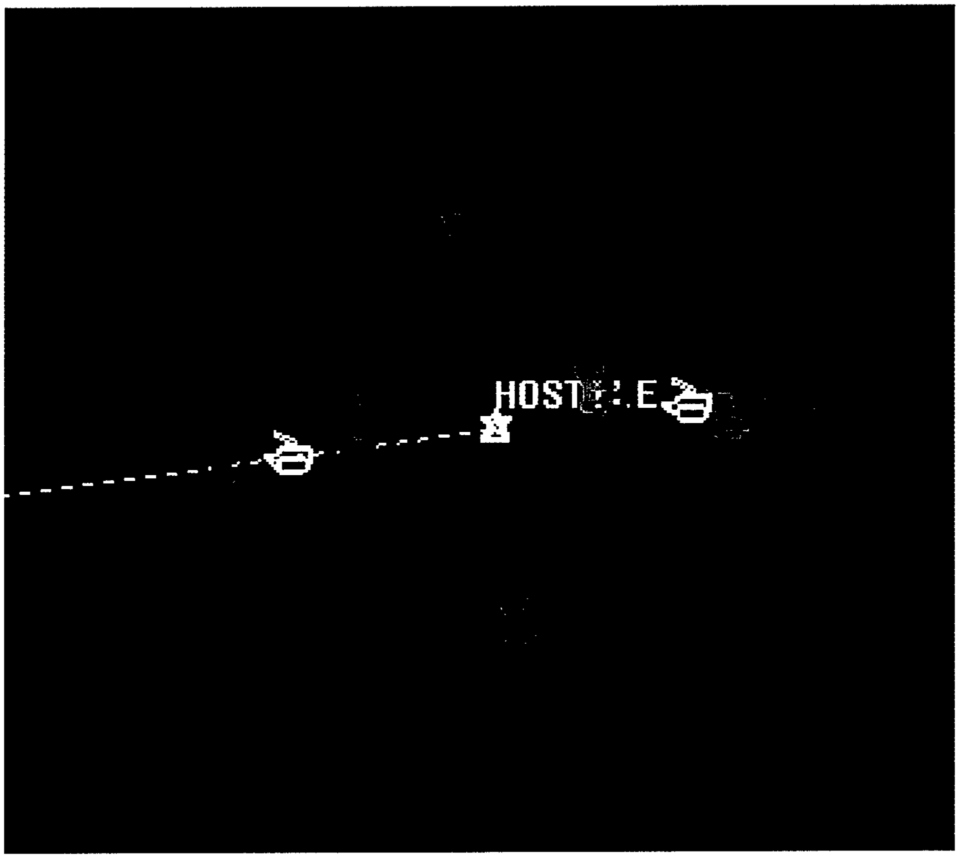

Figure 4. Close-Up Image of the Medium Threat Scenario Showing the Terminal Cruise Missile Flight Path, Enemy Air Defense Sites, and the Hostile Target.

E. HIGH THREAT

The high threat enemy laydown illustrated in Figure 5, consists of basic anti-aircraft guns, older Russian surface-to-air missile (SAM) systems, newer Russian surface-to-air missile (SAM) systems and hand-held surface-to-air missile launchers (MANPADS) grouped along the LAM's flight path to the target. The air defenses are placed to protect the target as if it were something as important as a theater ballistic missile site, command post, or headquarters building, since the LAM's proposed mission is to attack a variety of moving or stationary targets. The air defense weapons are the same as the low and medium threat laydowns with the addition of a couple of unclassified Russian SAM systems upgrades. Again, each model of anti-aircraft gun, SAM, or MANPAD was entered into EADSIM by using the appropriate sensors, weapons, rule sets, and systems described previously. The DD 21 in the high threat scenario is 120 kilometers, 65 nautical miles, offshore. The high threat target is approximately 540 kilometers, 292 nautical miles, from the ship.

Figure 5. Detailed Terrain Image of the High Threat Scenario Showing DD 21 Launching Platform, Cruise Missile Flight Path, Enemy Air Defense Sites, and Hostile Target.

Figure 6 reveals a closer look at the tight defenses around the intended hostile target, represented by a yellow star, in the high threat scenario. The cruise missile's flight path is the white dotted line entering from the bottom of the Figure and traversing through the air defense sites to the hostile target. Each different color represents a different type of air defense site.

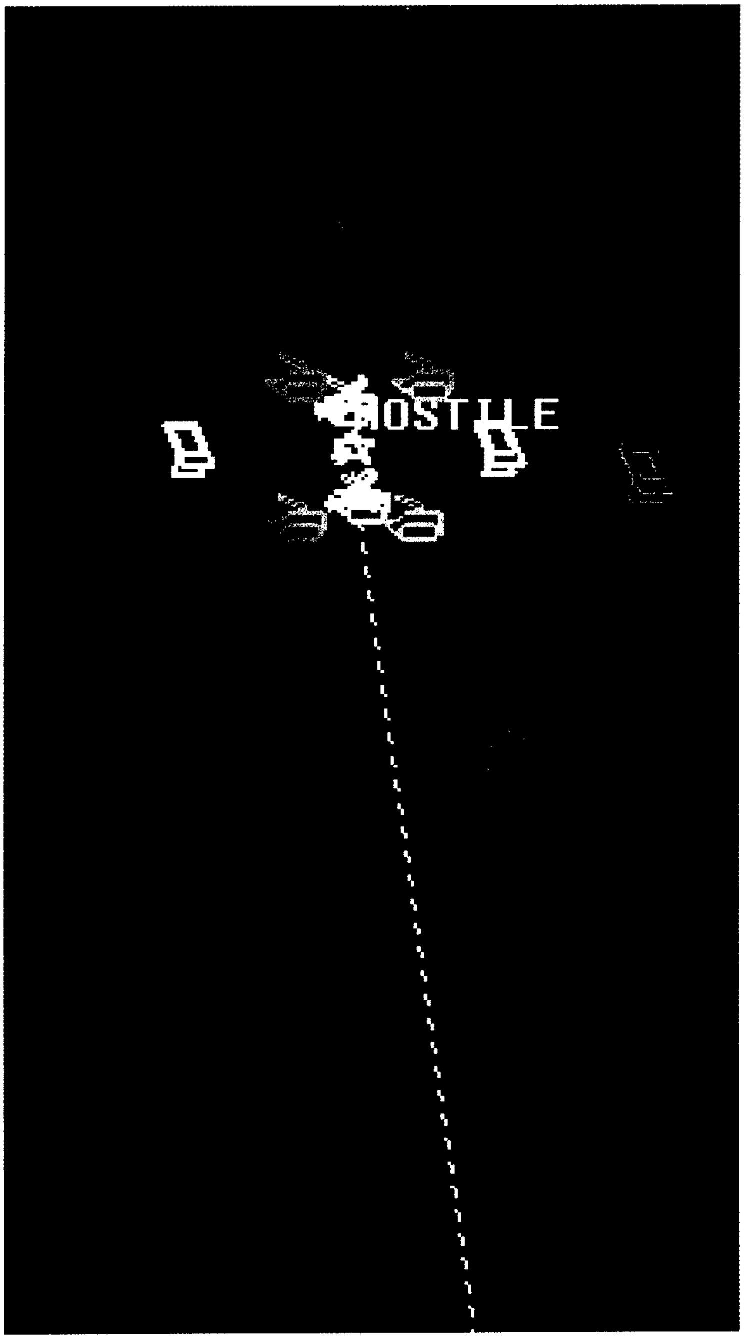

Figure 6. Close-Up Image of the High Threat Scenario Showing the Terminal Cruise Missile Flight Path, Enemy Air Defense Sites, and the Hostile Target.

F. VARIABLES

For each scenario, a variation of the LAM is run against each threat level thirty times. This allows us decent power in detecting alternatives so we can invoke the Central Limit Theorem, i.e., a normal approximation (Devore, 1995). The LAM has three primary independent variables that were altered. For the cruise missile variations, these independent variables are altitude, speed, and stealth. The ballistic missile LAM variants substitute trajectory for altitude.

1. Altitude

Altitude is varied differently for each speed category. The subsonic speed category has an initial lower bound of 50 meters above ground level (AGL) and is incremented to 100 meters above ground level, then by 100 meters to an upper bound of 600 meters AGL. In order to simulate the flight profile of a subsonic missile deploying BAT munitions, a popup terminal maneuver from the original altitude to 1,800 meters (6,000 feet) is performed. This maneuver was added to ensure the change in radar cross section is accounted for in these low altitude runs.

The bounds on the supersonic and hypersonic cruise flight profiles are incremented every 1,000 meters, beginning at 1,000 meters above mean sea level (MSL) and continuing to 6,000 meters MSL. MSL is used instead of AGL because super and hypersonic speed LAMs would not be able to control their altitude enough to make use of any terrain following. Furthermore, none of the examined LAM's routes forces it to fly through uneven terrain features.

Table 2 below shows all the test altitudes for the simulation runs in each scenario of the cruise missile LAM variants.

Flight Profile	Meters	Feet
Subsonic	50	164
Subsonic	100	328
Subsonic	200	656
Subsonic	300	984
Subsonic	400	1,312
Subsonic	500	1,640
Subsonic	600	1,968
Supersonic and Hypersonic	1,000	3,280
Supersonic and Hypersonic	2,000	6,562
Supersonic and Hypersonic	3,000	9,842
Supersonic and Hypersonic	4,000	13,123
Supersonic and Hypersonic	5,000	16,404
Supersonic and Hypersonic	6,000	19,685

Table 3. Flight Profiles and Altitudes Used to Test LAM Variants.

2. Trajectory

The ballistic flight profile cannot be modified for both the altitude and the speed variables simultaneously. As a result, the altitude for the ballistic flight profile is divided into two trajectories, depressed and lofted. The depressed and lofted trajectories are varied in each scenario because of the distance from the DD 21 to the target. The depressed LAM's apogee altitude ranges from a lower bound of 25,000 meters MSL (roughly 82,000 ft.) to a maximum upper bound of 33,000 meters MSL (roughly 108,000 ft.). The lofted trajectory LAM's apogee altitude ranges from a lower bound of 490,000 meters MSL (roughly 1,600,000 ft. or 304 mi.) to a maximum upper bound of 810,000 meters MSL (roughly 2,659,818 ft. or 504 mi.).

Tables 3 and 4 below depict the different trajectories and their average apogees, in meters, and dive angle, for each scenario threat level. The depressed trajectory keeps the LAM within notional apogee altitudes of current short-range ballistic missiles.

Scenario	Depressed (meters)	Depressed (feet)	Dive Angle (degrees)
Low Threat	31,000	101,705	25
Medium Threat	25,700	84,317	23
High Threat	33,000	108,267	20

Table 4. Apogees and Dive Angles for the Depressed Trajectory Ballistic Missiles.

The lofted trajectories are included in Table 4, but are very speculative in nature because of how high the apogee altitude is. The steeper terminal dive angle in the lofted trajectories, however, is better for LAM survivability. The steep dive angle prohibits detection of the missile because it exceeds the capabilities of most enemy surface-to-air missile systems and reduces time needed to acquire, track, and fire by the enemy SAM systems.

Scenario	Lofted (meters)	Depressed (feet)	Dive Angle (degrees)
Low Threat	622,000	2,040,676	83
Medium Threat	491,000	1,610,888	80
High Threat	808,000	2,650,911	80

Table 5. Apogees and Dive Angles for the Lofted Trajectory Ballistic Missiles.

3. Speed

The second independent variable is speed. Four general speed categories are a part of the speed independent variable. The speed categories are subsonic, supersonic, ballistic, and hypersonic. Subsonic refers to speeds less than Mach 1, and supersonic refers to speeds between Mach 1 and Mach 4. Ballistic refers to speeds around Mach 4, and hypersonic refers to speeds above Mach 5. The subsonic, supersonic, and hypersonic category missiles are modeled as cruise missiles, while the ballistic speed category missiles are modeled as ballistic missiles. The simulation test speeds are shown in Table 5 below.

Classification	Mach	Knots	Meters/Second
Subsonic	.65	420	216
Subsonic	.9	580	298
Supersonic	1.5	966	497
Supersonic	2.5	1,610	828
Supersonic	3.0	1,933	994
Supersonic	3.5	2,255	1,160
Ballistic	4.0	2,577	1,326
Ballistic	4.5	2,899	1,492
Hypersonic	5.0	3,221	1,657
Hypersonic	5.5	3,544	1,823

Table 6. Simulation Test Speeds Displaying Speed Category in Mach, Knots, and Meters per Second.

4. Stealth

The third independent variable is stealth. Stealth, in general, refers to radar cross-section (RCS) and infrared (IR) signature. Detection ranges are altered to represent a lower or higher RCS and/or IR signature. There are four categories for detection ranges indicated by percentages of the maximum detection range of the enemy sensor: 100%, 50%, 25%, and 10%.

G. SIMULATION RUNS

In order to run a different altitude variation in EADSIM for the subsonic, supersonic and hypersonic speeds, the cruise missile is edited for each different scenario. This includes changing the missile's altitude, speed, and terminal waypoints. The waypoints are set up to ensure a basic, but feasible, route is used. The first waypoint is set on the forward portion of the DD 21 at sea level, in order to represent a vertical launching system (VLS). The second waypoint is positioned between 1,000 – 2,000 meters from the DD 21 along the direct path to the target, at the altitude the LAM variant is supposed to have for the cruise portion of its flight. The third waypoint is modified to roughly simulate a 45-degree terminal dive angle to the intended target. The fourth and terminal waypoint is set either on the target or 1,800 meters above the target if the missile's flight path is lower than the needed altitude for BAT munition dispersal. The "popup" terminal maneuver is important to include in order to ensure that the enemy air defense sites have an opportunity to see any changes in the LAM's RCS as it rises to its dispersal altitude. If the flight path is above 1,800 meters, the BAT munitions will be dispersed as the missile passes through 1,800 meters, so the dive angle is unchanged.

The ballistic missile is modified in EADSIM by changing the amount of thrust and dry weight from the generic missile resident in EADSIM. Each trajectory and speed requires additional changes to the missile, since each scenario has the DD 21 a different range from the target. It is evident that the distance from the target directly influences the trajectory of the LAM. These differences are clearly seen in the apogee altitudes for each scenario shown previously in Tables 3 and 4.

EADSIM estimates the probability of survival for the various LAM alternatives as a function of the factors listed: altitude, speed, flight profile, detection range, and threat level. Statistics on the LAM's survivability are gathered and parametrically analyzed. The statistics include the probability the LAM is engaged by an air defense site, P_e and the probability the LAM is killed by any air defense site, P_k, aggregated for each LAM variant that is run thirty times using the Monte Carlo simulation capability in EADSIM. A script written by Michael Monius of the Joint Warfare Analysis Division at the Johns Hopkins University Applied Physics Lab extracts the relevant data and imports it into a text file. The text file is then opened in Microsoft Excel and a macro is recorded that extracts the lines of data that includes the scenario name, altitude, speed, detection range, P_e, and P_k for each of the 650 combinations (Walkenbach, 2000). Each line of data consists of 30 trials for each of the combinations for a total of almost 20,000 runs. The data is imported into S-Plus 2000 for visualization, comparison, and formal hypothesis testing.

III. RESULTS

There are several expected results from this thesis. The first is to establish a process to evaluate LAM survivability. The process is available for the Department of the Navy to use in their Analysis of Alternatives for the LAM. The process is established by defining what the elements and steps of the process are. Each step is defined in detail below. Finally, a wire diagram of the process is displayed to make it simple to see the flow of the process.

The second result is the analysis of the parametric data generated from the multiple EADSIM run combinations. The analysis looks for the important factors of LAM survivability and identifies where changing the independent variables no longer has much of an effect on missile survivability. Each of the independent variables, altitude or trajectory, speed, and stealth is discussed in terms of the MOE, P_k. It is important to understand that P_k is the probability the enemy air defense site kills the LAM, so the probability the LAM survives is 1- P_k.

Probability of engagement, P_e, is the MOP that was originally going to be used to help understand the MOE, P_k. After reviewing the relationships between the independent variables and P_e, it is apparent P_e is not helpful in predicting P_k. The values are skewed because the P_e is the average measured across all enemy air defense sites within the scenario. If the first site destroys the LAM, the later sites cannot engage the LAM. In many of the cases reviewed, the earlier sites did destroy the LAM and, therefore, skew the P_e values, making them lower than if the LAM made it through all the air defenses. Thus, P_e, as calculated in this thesis, is not a good MOP for this thesis.

The discussion centers on regression data with a smoothing spline line to display trends. After the discussion of the single independent variables with respect to P_k is complete, interaction terms are displayed and discussed using contour and box plots. The contour plots contain two of the variables on the x and y-axes and display contours in terms of P_k. The box plots display the middle 50% of the data, the median, and the interquartile range.

A. ESTABLISHING THE PROCESS

The process is constructed by merging logical data analysis steps with the multiple steps required in EADSIM to construct a new scenario. Figure 7 illustrates the basic steps required to create this process. Each of the seven steps in the process is discussed in greater detail below.

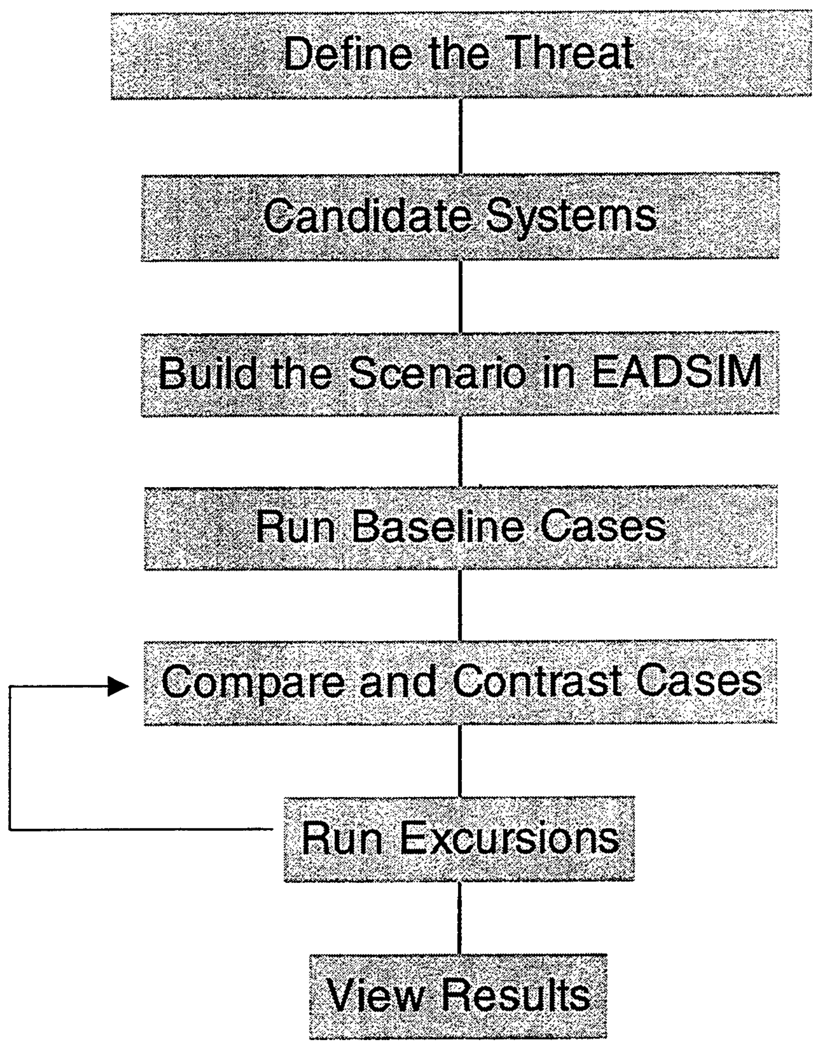

Figure 7. Wire Diagram Showing the Different Stages of the Process.

1. Defining the Threat

The first link of the process is defining the threats. In this research, the threat is classified as low, medium, and high. As described in the introduction, the low threat is defined as any third world country with older defensive systems. The medium threat is characterized by a more developed nation with a mixture of older and newer, more capable defensive systems. Finally, the high threat is a completely integrated defensive system that consists of the latest and greatest in defensive systems and their coordination amongst one another. In all cases, we assume an alerted threat with all systems 100% operational.

2. Candidate Systems

The second element of the process is evaluating the candidate systems. Each enemy air defense system consists of sensors, weapons, and rule sets. A sensor contains options for each of the detection criteria in a typical radar. These include sweep rate, slew rate, detection gates for absolute speed and altitude, field of view, azimuth, elevation, frequency and bandwidth. The weapons portion has lethality restrictions, like P_k percentage and lethal radius, along with maximum range values, maximum velocity values, launch constraints, and intercept constraints. Finally, the rule sets are specific to each operational phases of the engagement. These phases include target selection, launch, intercept, and reload. The mean and deviation of the phase timing are options included in these operational phases of EADSIM (Teledyne Brown, 1998).

3. Building the Scenario in EADSIM

The next step in establishing the process is to build the scenarios in EADSIM. Each scenario has terrain data imported, in this case, from a Detailed Terrain and Elevation Data, DTED, library at Johns Hopkins University Applied Physics Laboratory. The blue, friendly, and red, enemy, laydowns are built using the systems chosen in step two of the process. Each of these laydowns contains the systems and is represented by colored icons chosen by the person creating the scenario. In the cruise missile cases, the routes and waypoints are added. Similarly, in the ballistic missile cases, the ballistic missiles are created using the generic parameters available as the default cases in EADSIM (Teledyne Brown, 1998).

4. Run Baseline Cases

A run matrix is created using any available guidelines or specifications. This thesis incorporates several ideas that the Advanced Land Attack Missile program office, and Johns Hopkins University APL have generated. For the cruise missile cases, the waypoints, altitudes, and speeds are changed for each specific LAM variant and simulated 30 times. The ballistic missile cases are changed from the generic ballistic missile case in EADSIM to accommodate different distances to the target, trajectories, and speeds.

5. Compare and Contrast Cases

For each set of 30 simulations, the data on all the engagements is gathered in EADSIM. A script written in UNIX extracts the data from EADSIM and creates a generic text file. A cursory review of the data is conducted for the text files. If any of the specific runs contain curious or interesting data, the run is looked at in more detail in EADSIM. EADSIM allows the user to view each run of the group of 30 by itself. Reviewing the run allows the user to see each enemy air defense sensor acquisition and weapon engagement on the LAM graphically, similar to what Figures 1, 3, and 5 depict. At any time during the run, the perspective can be zoomed in or out and the playback can be paused for distance measurements to ensure the scenario is working properly (Teledyne Brown, 1998). Then, the data is imported into Microsoft Excel and a macro is run to average the P_e and P_k values over the 30 simulations (Walkenbach, 2000). The data is subsequently compiled into a single spreadsheet with all the pertinent data to this thesis, for easier viewing. These values are imported into S-Plus 2000 as data sets for parametric analysis, displaying various graphs and calculating hypothesis tests.

6. Run Excursions

Excursions may need to be run if interesting or unexplainable breakpoints are found when comparing and contrasting the baseline cases. Excursions allow the analyst to narrow the focus on the independent variables in question and then run them through EADISM again. If excursions are run, we go back to step 5 of the process.

7. Results

After all the excursions are run, we analyze the results in detail, record the results, and report any conclusions found.

B. ANALYSIS OF THE PARAMETRIC DATA

After the process is defined, data is tested to verify that the process works. As discussed, the data is entered into EADSIM scenarios and run using a Monte Carlo simulation with 30 replications. For example, one of the specific LAM variants replicated 30 times in each threat level scenario has the parameters of 1000 meters in altitude, Mach 3.0, and 100% of the maximum detection range for all specific enemy air defense sites. The analysis is grouped according to the independent variables with each threat level scenario usually represented in graphical form. Altitude, trajectory, speed, and stealth are the groupings, followed by the interactions between them.

The analysis is a combination of graphical regressions with spline smoothers, contour plots, and box plots. The raw data is also an integral part of the analysis, but only displayed if no regression or plot shows anything significant. Hypothesis tests are used to determine relationships between independent variables and the response variables, P_e and P_k.

Graphical regressions show all the groups of 30 runs together on axes that have the same scale. In addition to the regression graph, spline smoothers are included on the graphs to reveal trends in the data. The smoothing splines in S-PLUS are cubic equations computed by putting together a sequence of local cubic polynomials (MathSoft, 1999).

Contour plots are flat two-dimensional representations of three-dimensional data. The lines on the contour plot indicate locations of equal magnitude, in our case Pk. Contour plots show maxima and minima along with the slope of the surface in different regions on the plot. The closer together the lines are, the steeper the slope is. (MathSoft, 1999)

Box plots graphically display the median and interquartile range (IQR) of the data. The IQR is the middle 50% of the data, meaning all the data from the first quartile to the third quartile. Vertical lines from the IQR extend to adjacent values, but not more than 1.5 IQR beyond the quartiles. Any outliers are graphed individually as small circles beyond the vertical lines. (Hamilton, 1992)

1. Altitude (Cruise Missiles Only)

Altitude is the first independent variable that is discussed. It is only valid for the cruise missile LAM variants, because trajectory is used in the ballistic missile LAM variants. Figure 8 shows P_k versus altitude for the low, medium, and high threat level scenarios in a single smoothing spline plot. The symbols represent various speeds and detection ranges.

Recalling from Table 2, the altitudes ranged from 50-600 meters for the subsonic runs. These are grouped together in Figure 8 in the upper left hand corner with high probabilities of kill, P_k. The lower altitudes, and subsequent slower speeds on the subsonic flight profile missiles, allow the enemy air defense site more time to engage these LAM variants.

The low threat scenario is the only break from the steady 1.0 P_k in these subsonic runs, which is a direct reflection of the simplicity of its enemy air defenses. Figure 8 displays decreasing P_k as altitude increases for the low and medium scenarios. Both smoothing splines for the low and medium scenarios stop decreasing rapidly at greater than 4,000 meters in altitude, suggesting 4,000 meters is a possible transition point for the low and medium threat level scenarios. This finding is contrary to intuition and may be due to the lack of terrain masking that normally allows lower altitude cruise missiles to successfully make it to the target. In the high threat level scenario, however, no cruise missile variant is successful on its own against an alerted, ready threat.

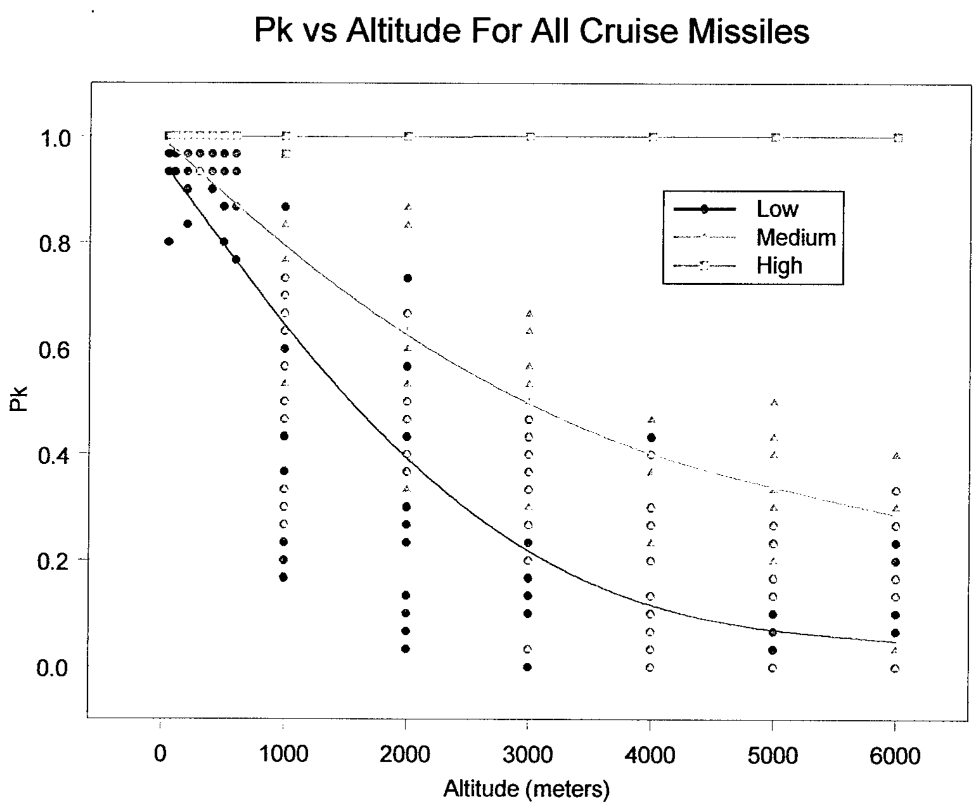

Figure 8. P_k versus Altitude For All Cruise Missiles For the Three Threat Levels. No Cruise Missiles Penetrated the High Threat Level Air Defenses.

Since all the subsonic runs are grouped together with a high probability that they are killed by enemy air defenses, they are removed in Figure 9. When the subsonic runs are removed, the spline smoother forms gradual curves for the low and medium threat level scenarios with an apparent maximum inflection at about 4,000 meters. The high threat still remains constant with a P_k of 1.0, while the medium scenario decreases monotonically from 0.65 to 0.3 P_k and the low scenario decreases from 0.4 to 0.05 P_k. Similar to Figure 8, P_k continues to decrease as altitude increases for the low and medium threat scenarios, while the high threat scenario, again, remains constant.

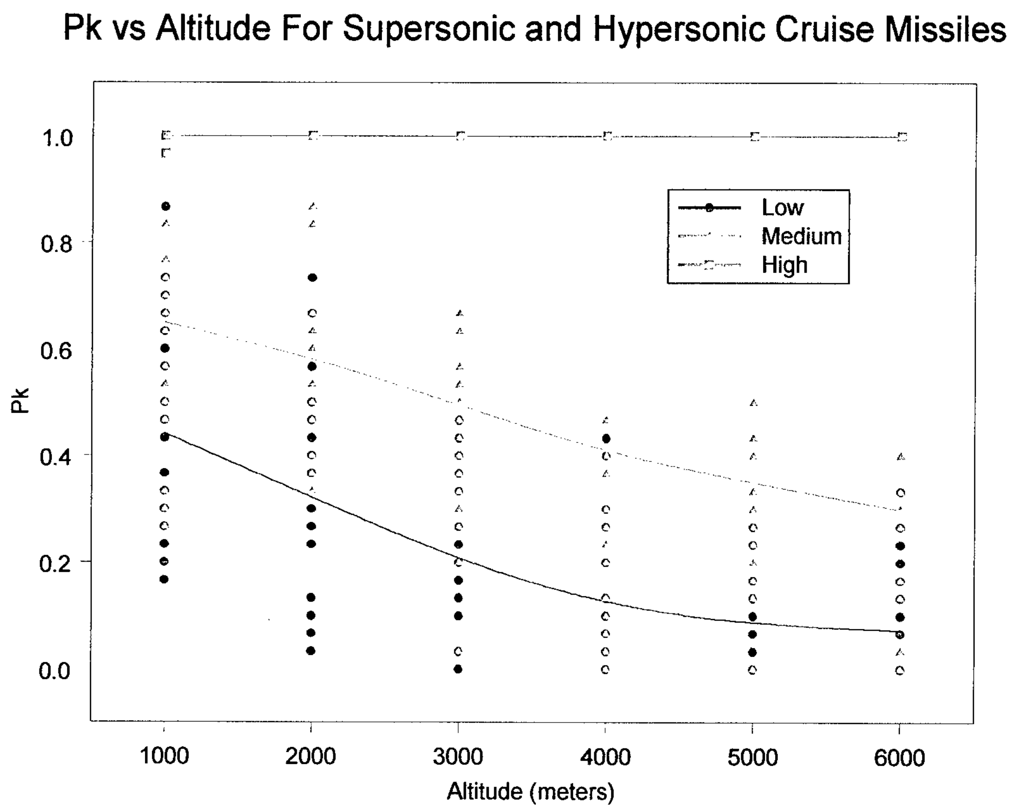

Figure 9. P_k versus Altitude For Supersonic and Hypersonic Cruise Missiles. The Low and Medium Threat Scenarios Show LAM Survivability Increasing as Altitude is Increased.

2. Trajectory (Ballistic Missiles Only)

Trajectory is used as a substitute for altitude in the ballistic missile scenarios. Trajectory is significant in only some of the scenarios. In the low and medium threat scenarios, the depressed trajectory scenarios have lower P_k values than the lofted trajectory scenarios. This may only be a result of the stochastic modeling. The results in the low and medium scenarios are in direct contrast to the results of the high threat scenario, as illustrated in Table 7. The lofted trajectory is favorable in the high threat scenario. This may be because of the steep dive angle (between 80 – 83 degrees) of the LAM. The steep dive angle limits the amount of time the LAM is "in the envelope" of the air defense site. The low and medium threat scenarios contain fewer air defense sites that can detect and fire upon the LAM because of the nature of the speed and trajectory of a ballistic missile. This may explain the apparent indifference to the depressed and lofted trajectories. Table 7 below shows the average P_k values for the depressed and lofted trajectories in each threat level.

Scenario	Depressed	Lofted
Low Threat	0.1075	0.1625
Medium Threat	0.1888	0.2675
High Threat	1.0	0.345

Table 7. Average P_k Values Against LAMs with Depressed and Lofted Trajectories For Each Threat Level.

3. Speed

Speed is the next independent variable discussed. It is valid for both the cruise and ballistic missile LAM variants. We again look at regression data fitted with a spline smoother for the low, medium, and high threat level scenarios.

a) Cruise Missiles

Figure 10 is the aggregation of all the threat levels in one figure. It is the graph of P_k versus speed for all the cruise missile replications. It illustrates the general idea of P_k decreasing as speed increases. This supports logical conclusions about speed and LAM survivability. As the speed increases, enemy air defense sites have less reaction time and can fire fewer SAMs at the inbound LAM. We also see from Figure 10 that the data points vary greatly in their range of P_k. The smoothing spline line begins at 1.0 P_k when speed is a subsonic 460 knots and ends at 0.4 P_k when speed is a hypersonic 3,544 knots. Because of the varying range of the response variable, each scenario is separated.

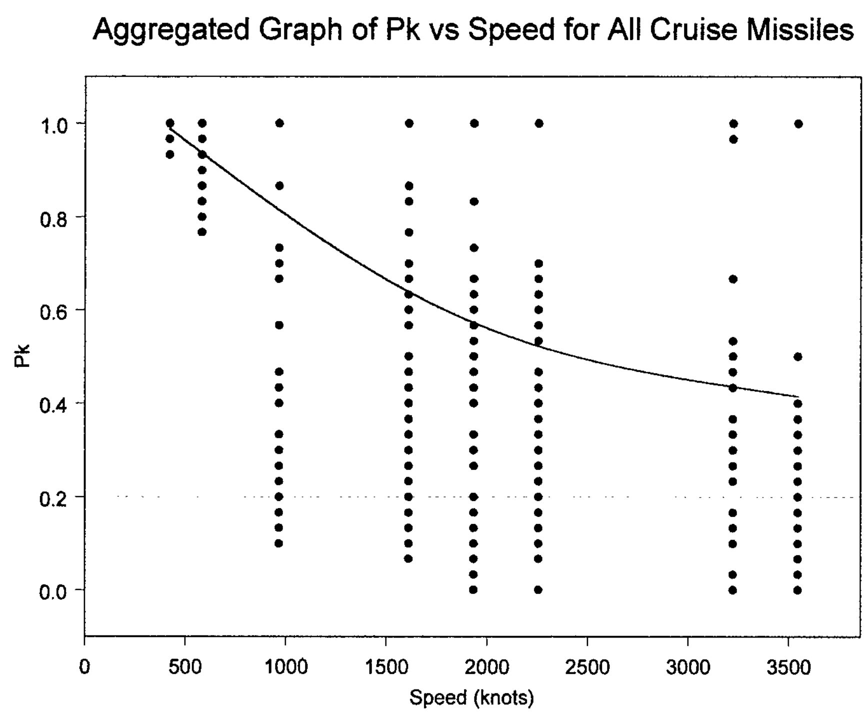

Figure 10. Aggregated P_k versus Speed For All Cruise Missiles As Speed Increases, LAM Survivability increases.

Because each scenario is presented individually in Figure 11, it is easy to see how the high threat scenario inflated the smoothing spline P_k values in Figure 10. The low threat level scenario starts with a P_k of 0.93 at 460 knots and decreases to about 0.07 P_k at 3,544 knots. The medium scenario starts with a P_k of 1.0 at the 460, 580, and 966-knot speeds, which are hidden behind the high threat scenario red squares, and ends with 0.2 P_k. The low and medium threat level scenarios illustrated in Figure 11 appear to have breakpoints in their respective P_k curves around the supersonic 1,933 knots (Mach 3.0) and 2,255 knots (Mach 3.5) speeds. Additionally, as expected, the P_k values for the low scenario remains less than P_k for the medium scenario throughout the range of speeds. The high threat scenario, however, remains unchanged with a P_k of 1.0.

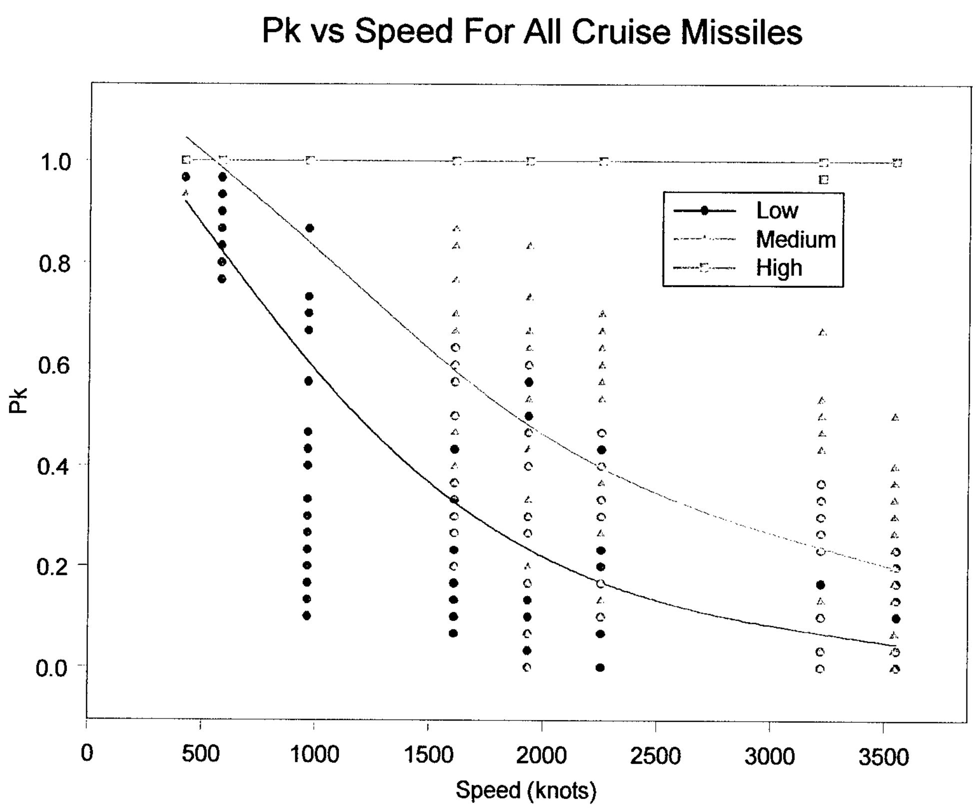

Figure 11. P_k versus Speed For All Cruise Missiles. As Speed Increases, LAM Survivability Increases For the Low and Medium Threat Levels.

When the subsonic runs are deleted, the low threat scenario smoothing spline flattens out quite a bit. In Figure 11, the beginning P_k value is greater than 0.9, while in Figure 12 below, it is reduced to 0.4 P_k. The medium threat scenario depicts a much more pronounced "knee" at the supersonic speed of 2,255 knots than the gradual descent in Figure 11 with the subsonic runs included. The high threat scenario remains constant with a 1.0 P_k. The medium threat scenario triangles at 966 knots are hidden behind the high threat red square at 1.0 P_k.

All the regressions run with speed as the individual variable versus P_k show that subsonic speeds have very high P_k values. As modeled in this thesis, subsonic speed LAMs have a low probability of survival against any threat level of enemy air defense because terrain-masking and air defense site avoidance techniques are not modeled.

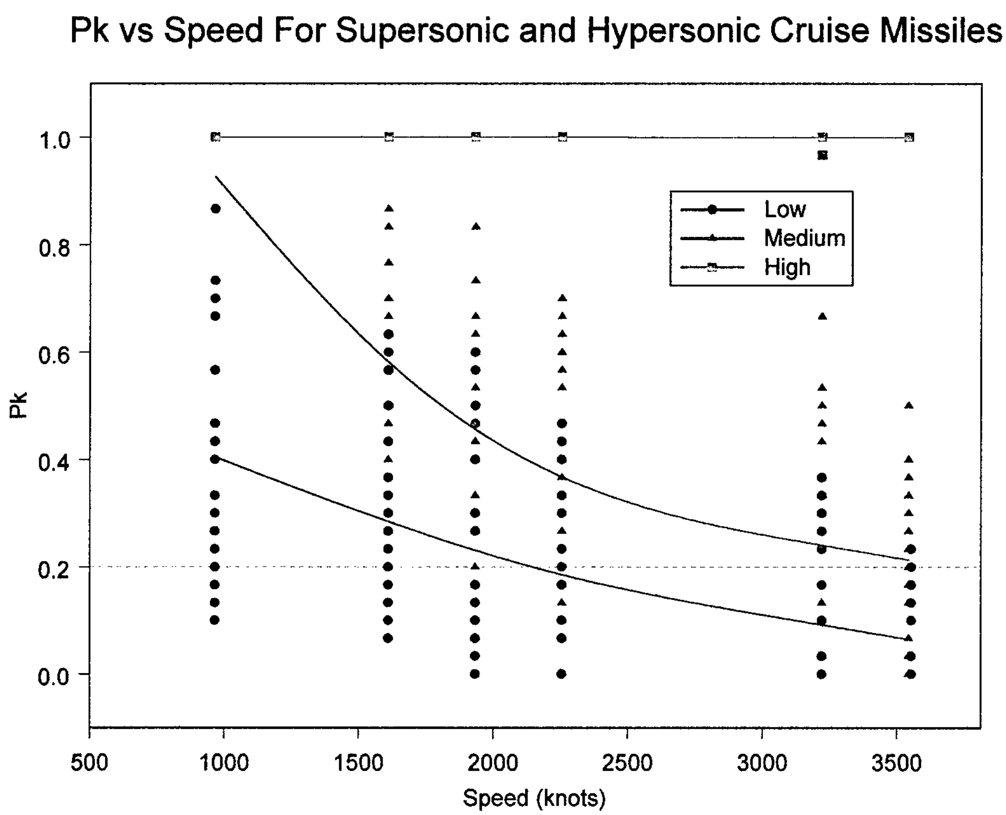

Figure 12. P_k versus Speed For Supersonic and Hypersonic Cruise Missiles. The Low and Medium Threat Levels Show LAM Survivability Increasing as Speed Increases.

b) *Ballistic Missiles*

Because the ballistic missile runs have only two speeds, a box plot of the data is more helpful in illustrating the similarity or differences of the two speeds. The middle 50% of the P_k values for the 2,577-knot (Mach 4.0) speed lie between 0.5 and 0. Similarly for the 2,899-knot (Mach 4.5) speed, the middle 50% lies between 0.47 and 0. Figure 13 below shows very little difference over the breadth of cases run in the P_k for the two speeds used in the ballistic missile scenarios.

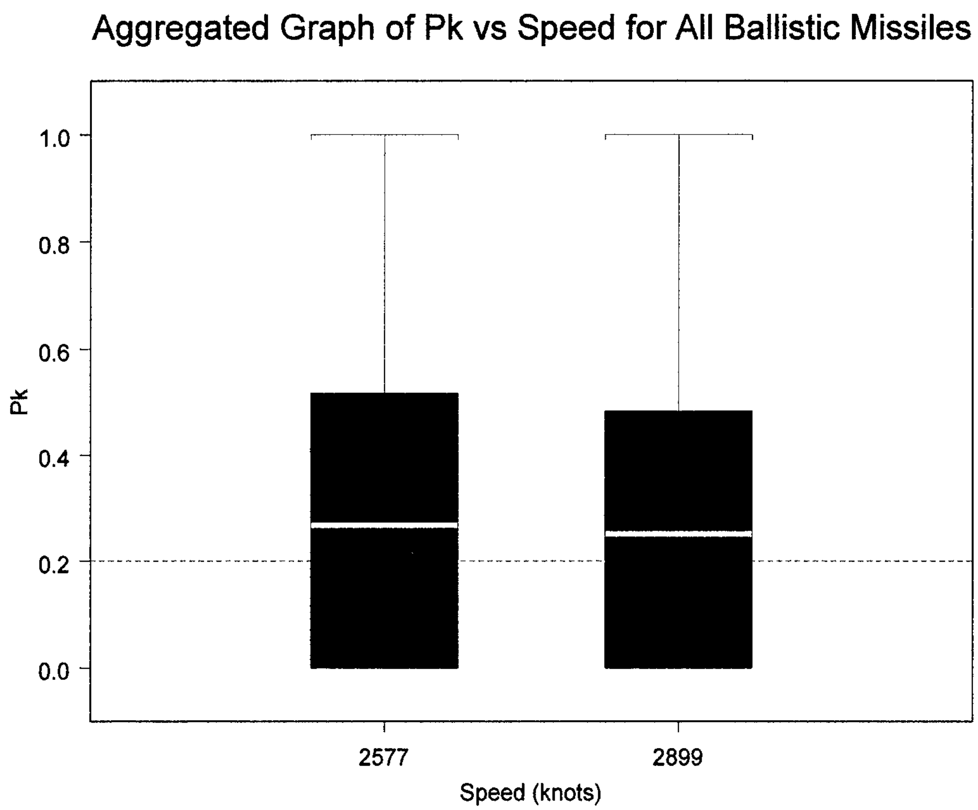

Figure 13. Box Plot of P_k versus Speed For All Ballistic Missiles Aggregated for All Threat Level Scenarios. Both Speeds have Similar Plots.

4. Stealth

Stealth is the final independent variable discussed. Stealth is the minimization of radar cross-section and infrared signature that most limit enemy detection opportunities. RCS and IR signature are functions of the aspect angle with respect to the target. Stealth is very complicated to model explicitly in EADSIM. Since this thesis is unclassified, the detection ranges of the enemy air defense sites are altered to simulate a portion of stealth. The 100% detection range is based on the maximum range of the air defense site. The RCS of the LAM variants is sufficiently large, which allows the enemy air defense sites to detect the LAM at the site's maximum range. As the detection range is decreased, the time the LAM is in the enemy site's envelope is decreased. This models the same effect as a reduced RCS and/or reduced IR signature.

a) Cruise Missiles

The fitted cubic splines are almost flat, but have a small dip at the 10% detection range in all the scenarios. Figure 14 shows that P_k remains constant for the high scenario, but the low and medium threat scenarios appear to have small downward trends at the 10% detection range. This suggests that over the detection ranges initially examined, detection range does not affect missile survivability. Of course, if the detection range is small enough, the LAM will make it through the air defenses.

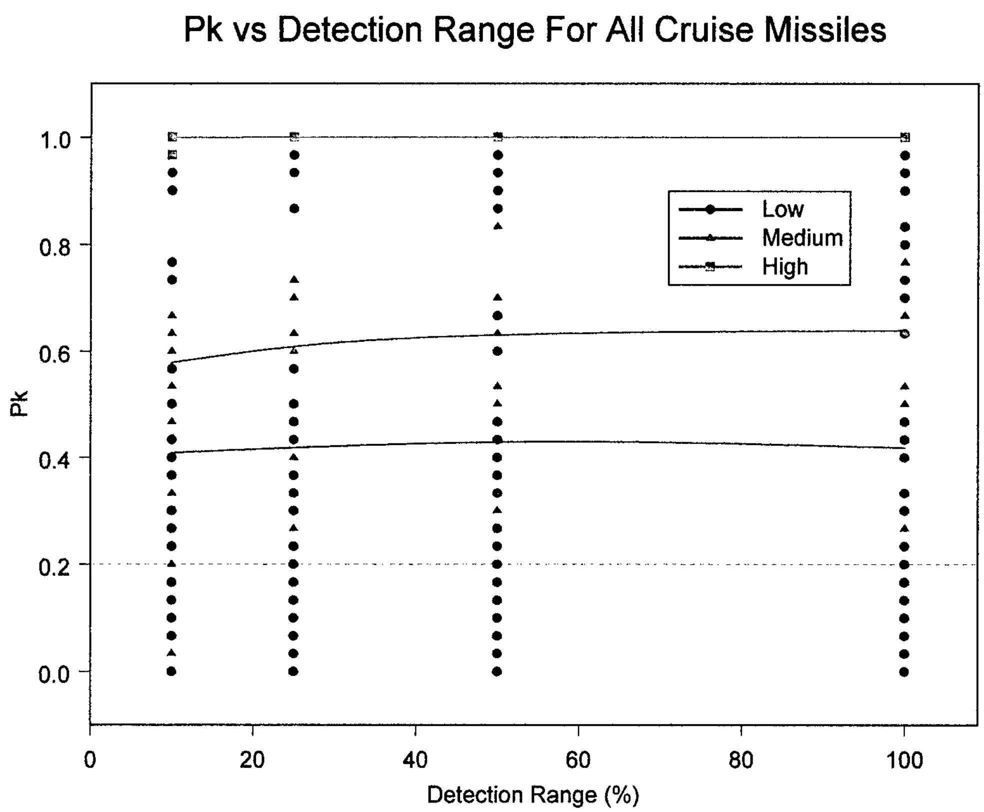

Figure 14. P_k versus Detection Range For All Cruise Missiles. LAM Survivability For All Three Threat Levels Remains Relatively Constant For the Detection Ranges Examined Above 10%.

An aggregated graph of all cruise missiles for all the scenarios paints a similar picture to Figure 14 above. It shows a relatively straight-line beginning with P_k = 0.7 at 100% detection range and declining slightly to about 0.65 at 10% detection range. As a result of the seemingly downward trend at 10% detection range for Figure 14 and the aggregated cruise missiles, extra simulation runs for the high threat scenario were run and the results are displayed in Figure 15 below. The speeds for these excursion runs are 966, 1,610, and 1933 knots. The 966-knot speed is too slow to make the lower detection range significant, but the 1,610 and 1,933-knot simulation runs at 1% detection range produced P_k values of 0. We infer that the drastic change in P_k for the high threat level scenario will also be seen in the low and medium threat scenarios since the high threat scenario contains more in-depth air defenses in both quantity and sophistication of the enemy air defense sites.

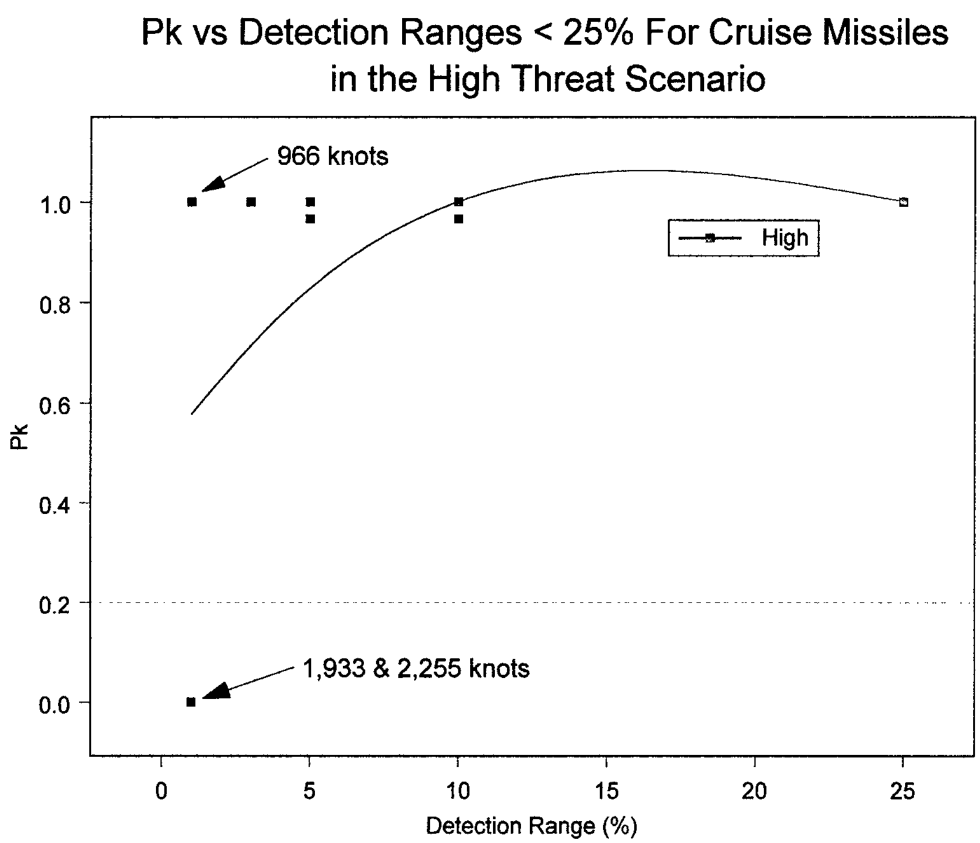

Figure 15. P_k versus Detection Ranges of 25% and Below For Cruise Missiles in the High Threat Scenario. Speed Must be ≥ 1,933 knots in Order to Lower the P_k at 1% Detection Range.

b) *Ballistic Missiles*

This section discusses the detection range independent variable in the ballistic missile scenarios. All three threat level scenarios exhibit steady declines in P_k as the detection ranges decrease. The low and medium threat scenarios have a 0.0 P_k value at 10% detection range, which is obscured by the red square for the high threat scenario. The high threat scenario, however, only declines from a 1.0 P_k when a lofted trajectory is applied vice a depressed trajectory. The "depressed" text in Figure 16 points out the 1.0 P_k values for the 10 and 25% detection ranges using the depressed trajectory, while the "lofted" text shows the waterfall like decline in P_k when the 10% detection range and the lofted trajectory are combined. As detection range decreases, the number of engagements decrease and therefore, P_k decreases because the enemy air defense sites do not detect the LAM as quickly and thus have less time to engage them.

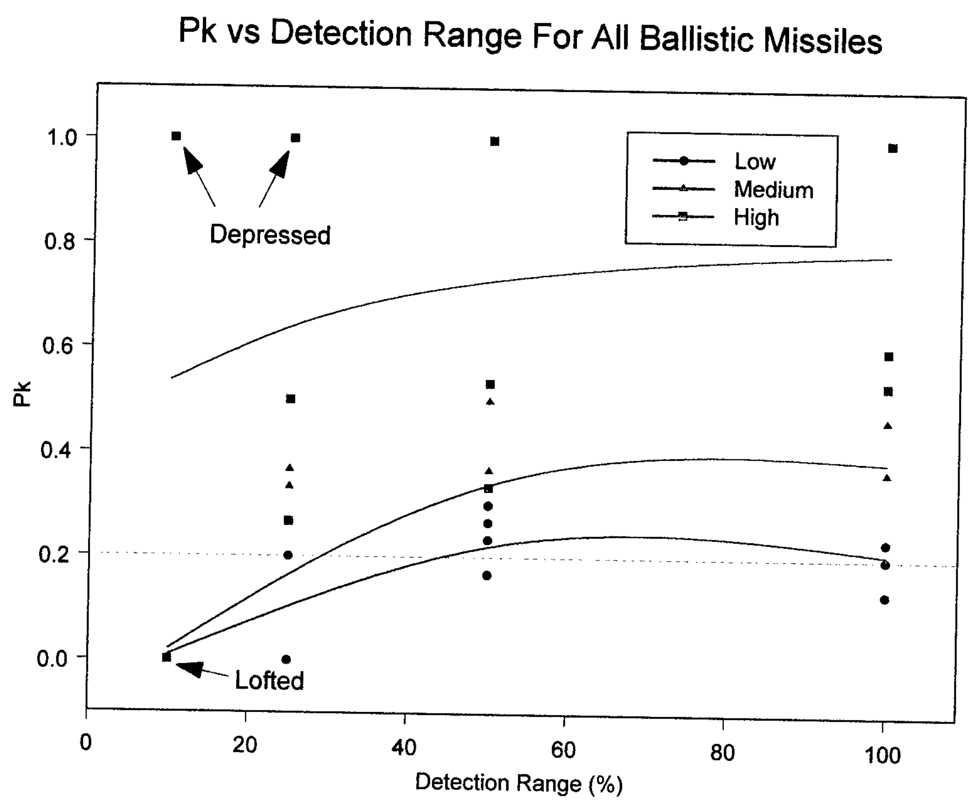

Figure 16. P_k versus Detection Range For Depressed and Lofted Trajectory Ballistic Missiles. The Lofted Trajectory LAM is Able to Survive in the High Threat Scenario.

5. One-Dimensional Summary

Reviewing the results for the one-dimensional analysis of the independent variables, it is apparent that the low and medium threat cruise missile scenarios are very similar to each other, but very different from the high threat cruise missile scenario. The cruise missile runs show that as altitude and speed increase, LAM survivability increases for the low and medium threat levels. Varying the stealth does not improve the survivability of the LAM in any of the threat level scenarios unless is reduced to 1% of the detection range, seen only in the excursion runs. The high threat scenario did not allow any LAMs to survive unless the detection range is reduced to 1% of the maximum range. The ballistic missile LAMs in the low and medium threat levels are more survivable with a depressed trajectory and, naturally, a low detection range. The high threat level scenario, however, produces survivable LAMs only if the trajectory is lofted and the detection range is 10% or less.

6. Altitude and Speed Interaction

Now that the independent variables have been examined individually, the two-dimensional findings are next. The two-dimensional figures allow us to visualize interactions between the variables. Altitude and speed is the first interaction pair discussed. Only the cruise missile LAM variants have this interaction term because trajectory is used as a substitute for altitude in the ballistic missile variants. All threat levels are outlined paying particular attention to the low and medium threat level scenarios. Tables 8 and 9 recount the altitude and speed combinations for the cruise missile LAM variants.

Altitude (meters)	50	100	200	300	400	500	600
Altitude (meters)	1,000	2,000	3,000	4,000	5,000	6,000	

Table 8. Altitude Combinations For Cruise Missile LAM Variants.

Speed (knots)	460	580	966	1,610	1,933	2,255	3,221	3,544

Table 9. Speed Combinations For Cruise Missile LAM Variants.

a) Cruise Missiles

There are several combinations of altitudes and speeds that meet the objective of 0.2 P_k, which is the same as an 80% chance the LAM variant survives to its target. The contour with a P_k value of 0.2 is dashed in Figure 17. The low threat scenario combinations that meet our objective are 6,000 meters and Mach 1.5, 5,000 and 4,000 meters and Mach 2.5 and greater, 3,000 meters and Mach 3.5 and greater, and 2,000 meters and Mach 5.5. It is important to focus on the general contour shapes. The data input are random variables and have sparse areas. Some of the fine detail is random variation or S-Plus trying to interpolate or extrapolate the data, particularly at the boundaries. Figure 17 below is not smooth, possibly because of randomness of the data or different interactions that cannot be seen from this contour plot alone. It does show the P_k values escalate rapidly as altitude decreases below 3,000 meters and speed slows below 1,500 knots. More systems are able to engage the LAM with success at the lower altitudes and speeds.

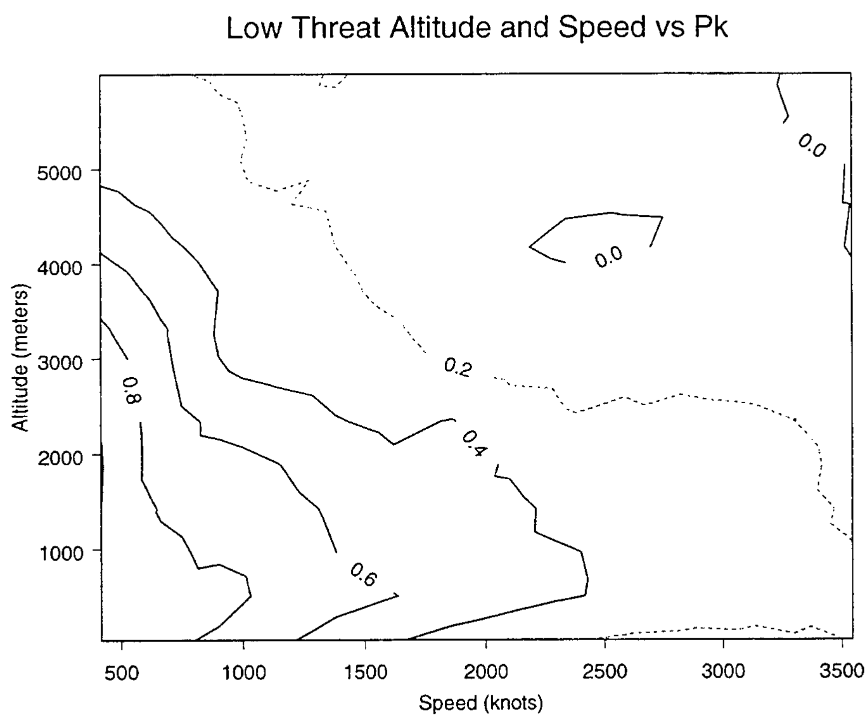

Figure 17. Contour Plot of the Low Threat Scenario. Altitude and Speed versus P_k. LAM Survivability Increases As Altitude and Speed Increase.

The medium threat scenario combinations that meet our objective are 6,000 meters and Mach 3.5 and greater, 5,000 meters and Mach 3.5, 5,000 meters and Mach 5.5, 4,000 meters and Mach 5.0 and greater. It is easy to see the odd shape of the 0.2 P_k contour in the top right corner of Figure 18. Upon closer inspection of the data, the 5,000 meters and Mach 5.0 simulation runs do have a higher P_k than the surrounding runs. This may be easily attributed to some randomness among the data, similar to what is discussed in the low threat scenario.

To explain some of the randomness, a standard error, SE, calculation is presented. $SE = \sqrt{\frac{p(1-p)}{n}}$; for our example p = .2 and the number of runs, n = 30, so $\sqrt{\frac{(.2)(.8)}{30}}$ = 0.073. It would not be unusual to see a result up to two standard errors from the true value, so $0.073 * 2 = 0.1461$. This means each P_k value can be +/- 0.1461. Therefore, we look at the general shape of the plot, rather than the fine detail. The contours also show that altitude does not matter when speed slows to below 1,500 knots. Figure 18 indicates there is an interaction between altitude and speed.

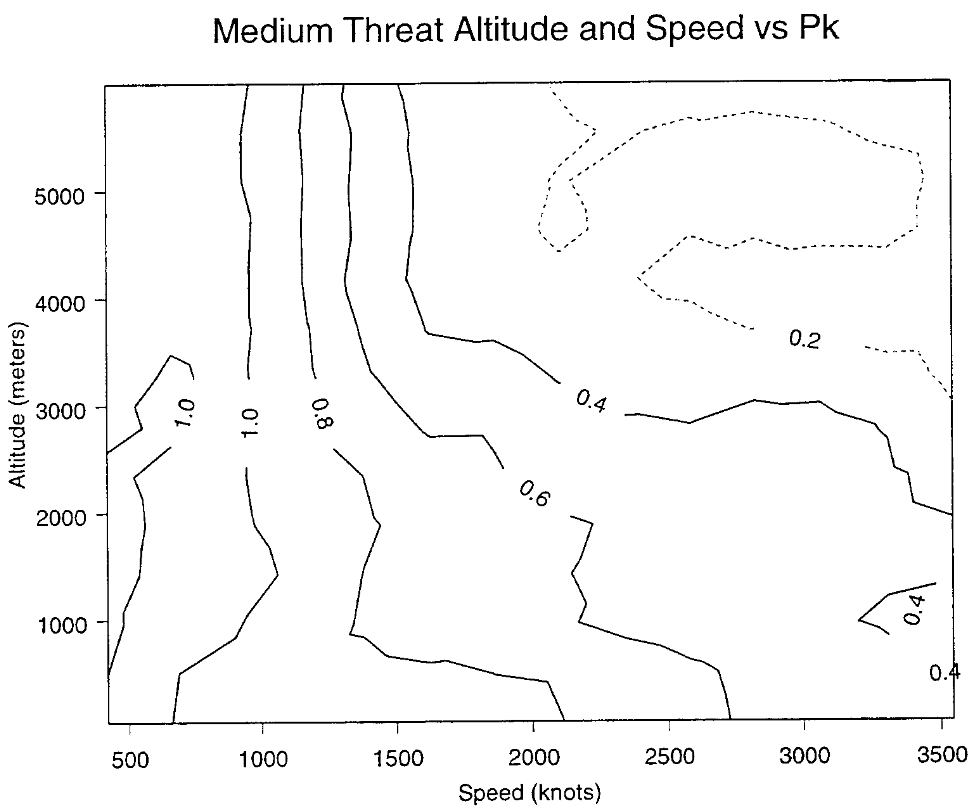

Figure 18. Contour Plot of the Medium Threat Scenario. Altitude and Speed versus P_k. LAM Survivability Increases as Altitude Increases ≥ 3000 meters and Speed Increases Above 1,610 knots.

The high threat scenario graph is not interesting (and thus not shown) because all the P_k values are 1.0. This suggests that no altitude and speed combinations have any interaction with each other in the high threat level scenario.

7. Trajectory and Speed Interaction (Ballistic Missiles)

This interaction is difficult to analyze. Since trajectory is only a variable in the ballistic scenarios, there is not much data to analyze. There are only two trajectory types and two speeds for the ballistic scenarios. Table 9 below shows the threat level of the scenario, trajectories, speeds, and their associated summed P_k values. All the scenarios have similar P_k values for the two speeds when the trajectory is constant. This suggests the speed is not interacting with trajectory for the ballistic missile LAM variants.

Scenario	Trajectory	Mach 4.0 P_k	Mach 4.5 P_k
Low Threat	Depressed	0.1	0.115
Low Threat	Lofted	0.1575	0.1675
Medium Threat	Depressed	0.1675	0.1925
Medium Threat	Lofted	0.3	0.235
High Threat	Depressed	1.0	1.0
High Threat	Lofted	0.35	0.34

Table 10. Trajectory, Speed, and P_k values for the Ballistic Missile LAM Variants. Low and Medium Threat Level Scenarios have Better LAM Survivability using Depressed Trajectories, while the High Threat Level LAM is Successful using a Lofted Trajectory.

Figure 19 shows a box plot of all the trajectory and speed data. As in Table 9, the two different speeds with the same trajectory have similar medians and IQRs. This indicates that the two variables, trajectory and speed, are independent of one another and therefore, have no interaction. The trajectory has the largest effect on P_k.

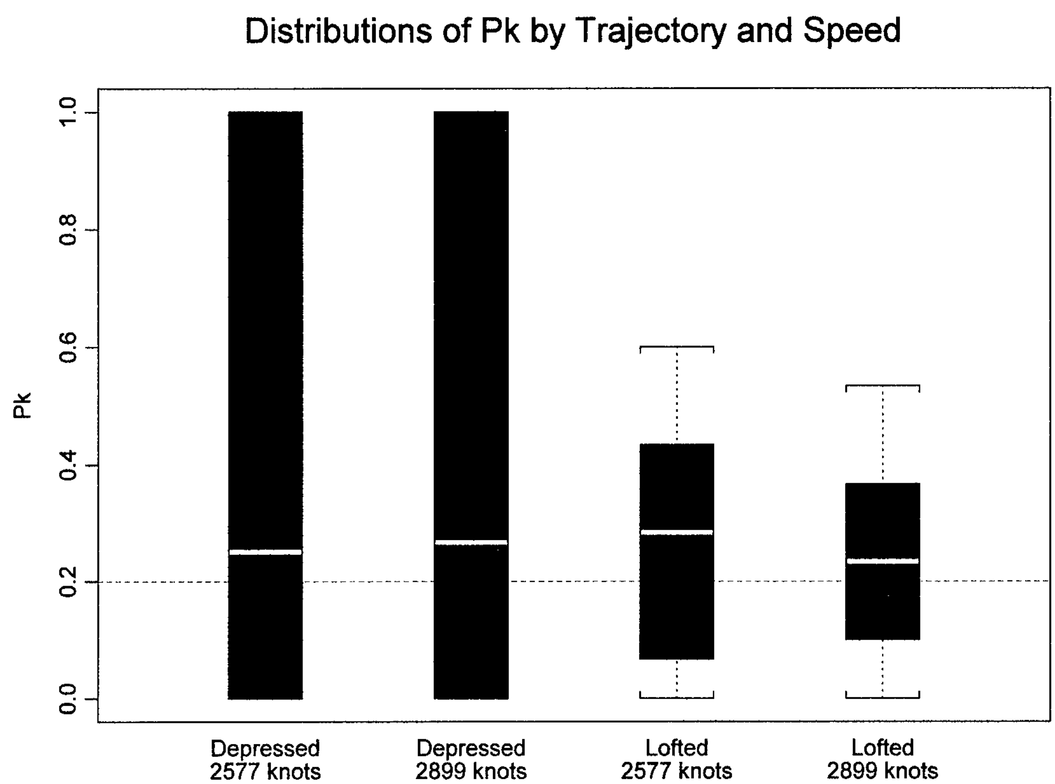

Figure 19. Box plot of P_k versus Trajectory and Speed There is no Interaction Between Trajectory and Speed.

8. Altitude and Stealth Interaction

Altitude and stealth is the next interaction term to consider. It is only valid for the cruise missile LAM variants.

a) *Cruise Missiles*

The smooth, straight contours of Figure 20 below, suggest that in the cases we observed, detection range is independent of altitude, hence there is no interaction between the two. This is to be expected since the detection range has little effect on the LAM's survivability. The only interesting region of Figure 23 is the hump around 2,000 meters that runs the length of the detection range axis. A closer look at the data reveals only minor differences between the P_k values of the simulation runs at 1,000 meters and the ones at 2,000 meters. The P_k values for the runs with an altitude of 3,000 meters and above are significantly lower than the ones using an altitude of 1,000 and 2,000 meters. This anomaly in the graph is likely due to standard error.

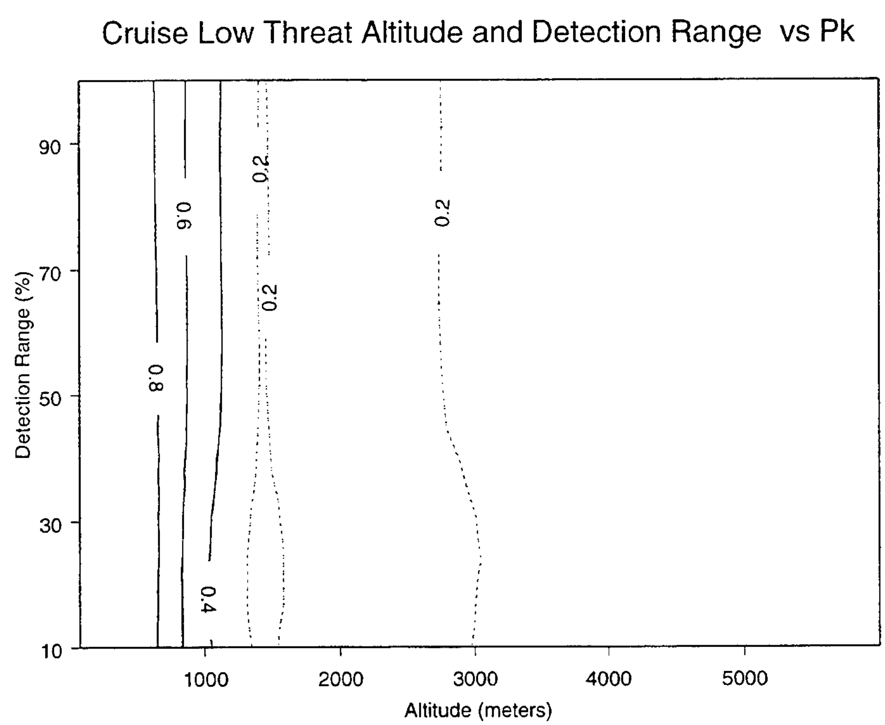

Figure 20. Contour Plot of the Low Threat Scenario. Altitude and Detection Range versus P_k. There is no Interaction Between Altitude and Detection Range.

The contours for the medium threat scenario in Figure 21 below seem to be independent, similar to the low threat scenario in Figure 20. This again suggests that detection range does not affect the P_k when interacting with altitude. The dashed line representing 0.2 P_k is only in the top right corner of Figure 21.

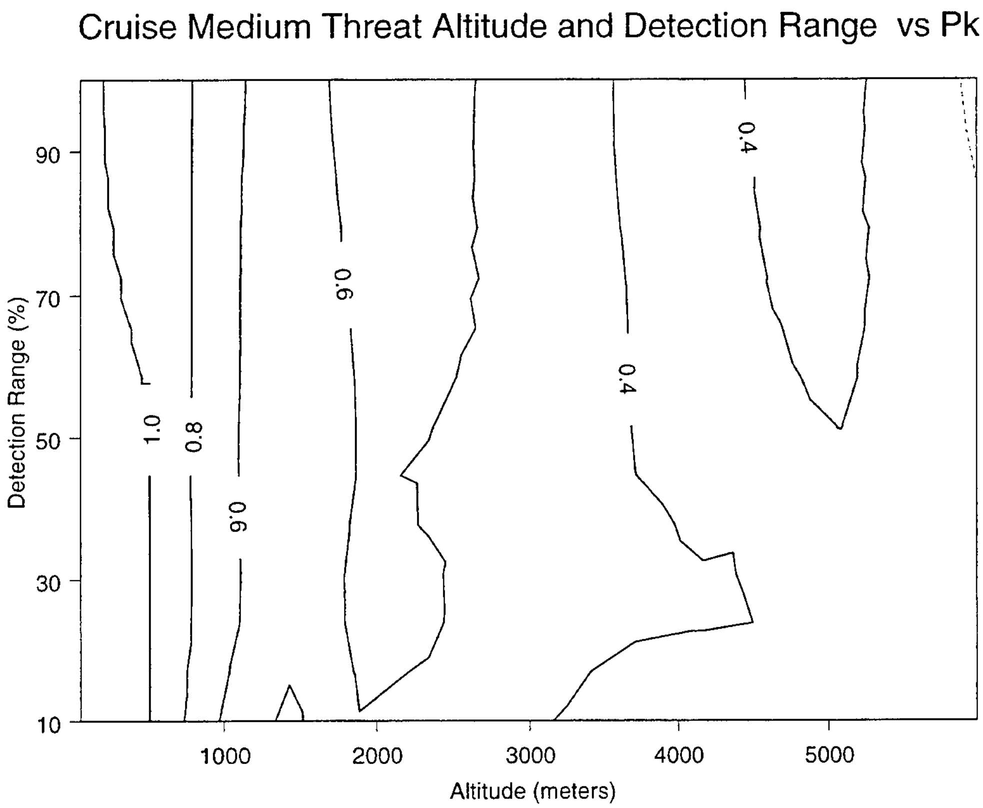

Figure 21. Contour Plot of the Medium Threat Scenario. Altitude and Detection Range versus P_k. There is no Interaction Between Altitude and Detection Range.

The high threat scenario illustrated in Figure 22 below, shows the only interesting area are the results of the excursion runs completed. After the simulation runs, any possible low P_k values are recorded only when the detection range is less than ten percent. The contours also gravitate toward the altitude of 5,000 meters, which is the constant altitude of the excursion runs. Thus, over the regions studied, we have not found evidence of an interaction between altitude and stealth.

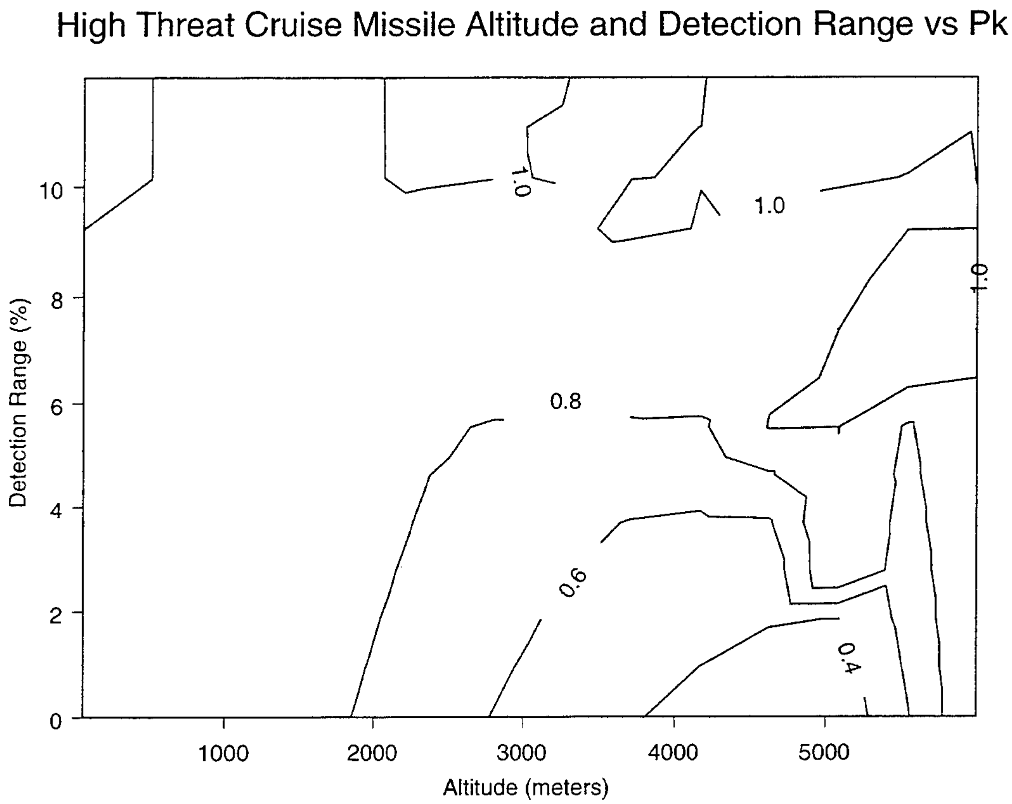

Figure 22. Contour Plot of the High Threat Scenario. Altitude and Detection Range versus P_k for Detection Ranges $\leq 10\%$.

9. Trajectory and Stealth Interaction

This interaction is for ballistic missile LAM variants only. All three threat level scenarios are discussed using box plots. Box plots allow each of the two trajectory and four detection range combinations to be compared easily.

a) Ballistic Missiles

Figure 23 shows a box plot for all the trajectory and detection range combinations. The depressed trajectory/10% detection range and the depressed trajectory/25% detection range combinations in Figure 23 illustrate a large IQR, yet have a median at 0 P_k. This suggests one of the scenarios has very different values from the others. In fact, when reviewing the raw data, the all the combinations of depressed or lofted trajectories and 10% detection range have P_k values of 0, except the high threat scenario. The large IQRs for all the depressed trajectory boxes in Figure 23 are because of the steady P_k value of 1.0 for the high threat scenario. The high threat level scenario has lower than 1.0 P_k only when the lofted trajectory is used. While not apparent in Figure 23, the low and medium threat scenarios have lower P_k values for the depressed trajectories. To illustrate the scenario difference, we look at each scenario in addition to the trajectory and detection range combinations.

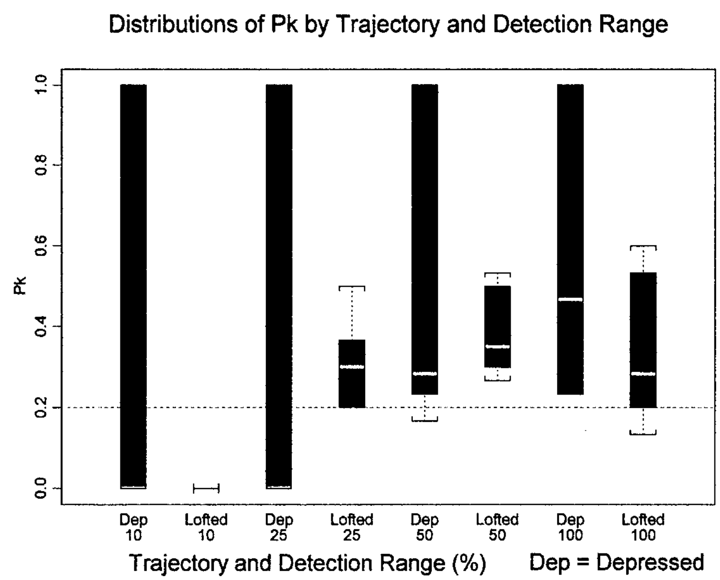

Figure 23. Box plot of P_k versus Trajectory and Detection Range For All Threat Level Ballistic Missiles.

As a continuation of Figure 23 on the previous page, Figure 24 shows the trajectory and detection range interaction for each scenario. The low threat scenario has very low P_k values for both the lofted and depressed trajectories. The depressed trajectory/100% detection range and the lofted trajectory/50% detection range are the only two combinations that are consistently above the 0.2 P_k success value. This means all the other combinations for the low threat scenario meet the 80% probability of survival for the LAM. The combinations of depressed trajectory/10% detection range, depressed trajectory/25% detection range, and lofted trajectory/10% detection range are viable options in the medium threat scenario. The only option less than 0.2 P_k in the high threat scenario is the lofted trajectory/10% detection range combination.

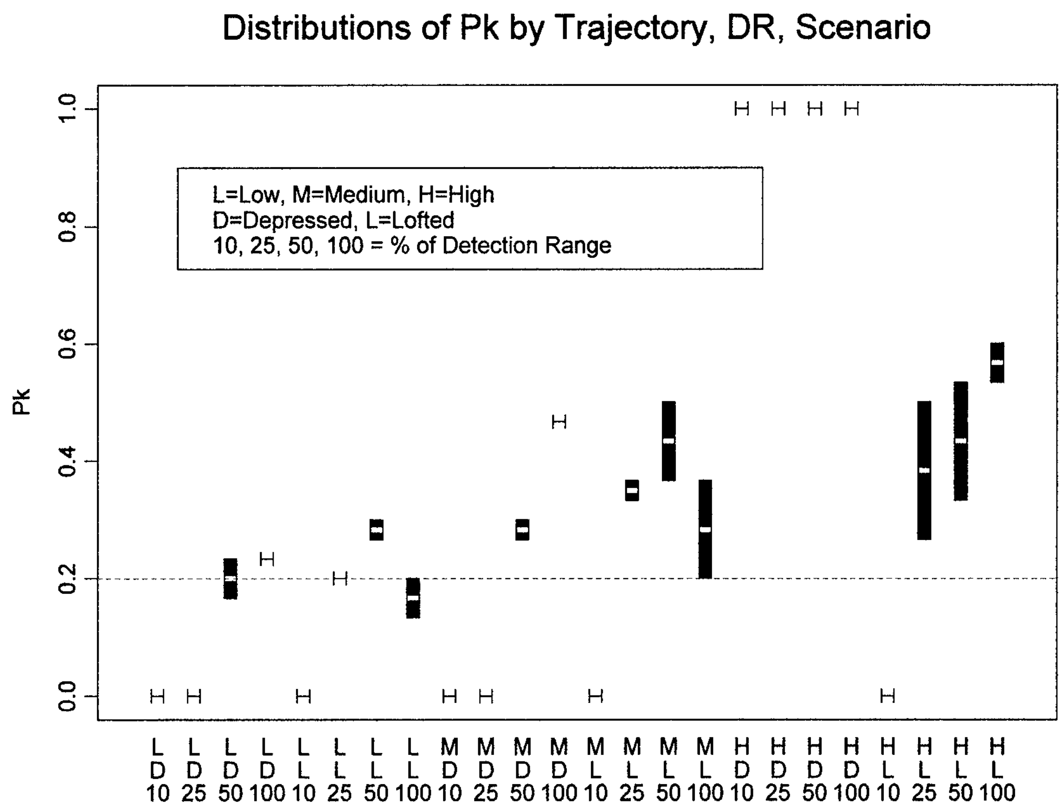

Figure 24. Box plot of P_k versus Trajectory and Detection Range for Low, Medium, and High Threat Level Scenario Ballistic Missiles.

10. Speed and Stealth Interaction

The speed and stealth interaction is discussed for both the cruise and ballistic missile LAM variants. Contour plots are used to discuss cruise missile LAM variants, while box plots are displayed for the ballistic missile variants. The cruise missile LAMs have eight different speeds depicted in Table 9 and four different detection ranges. The ballistic missile variants, however, only have two speeds.

a) Cruise Missiles

As seen in Figure 25, detection range does not seem to matter on the cruise missile runs in the low threat scenario. The slight decrease in the 0.2 P_k line in Figure 25 may indicate that P_k decreases when detection range is less than ten percent and speeds are less than 1,933 knots. Once again, the contours show that speed and stealth are fairly independent.

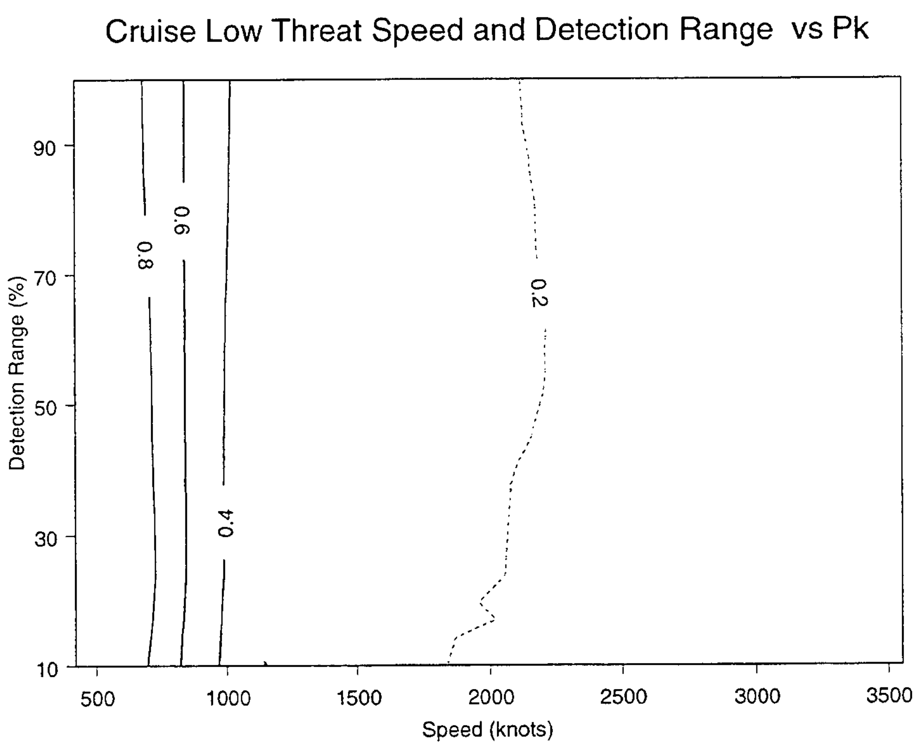

Figure 25. Contour Plot of the Low Threat Scenario. Speed and Detection Range versus P_k. There is no Interaction Between Speed and Detection Range in the Low Threat Scenario.

In the medium threat scenario, shown in Figure 26 below, speed must be in the 3,500 knot range, or be at least 3,221 knots and have a detection range less than or equal to ten percent in order to fall within the 0.2 P_k area. This data seems to be more stochastic.

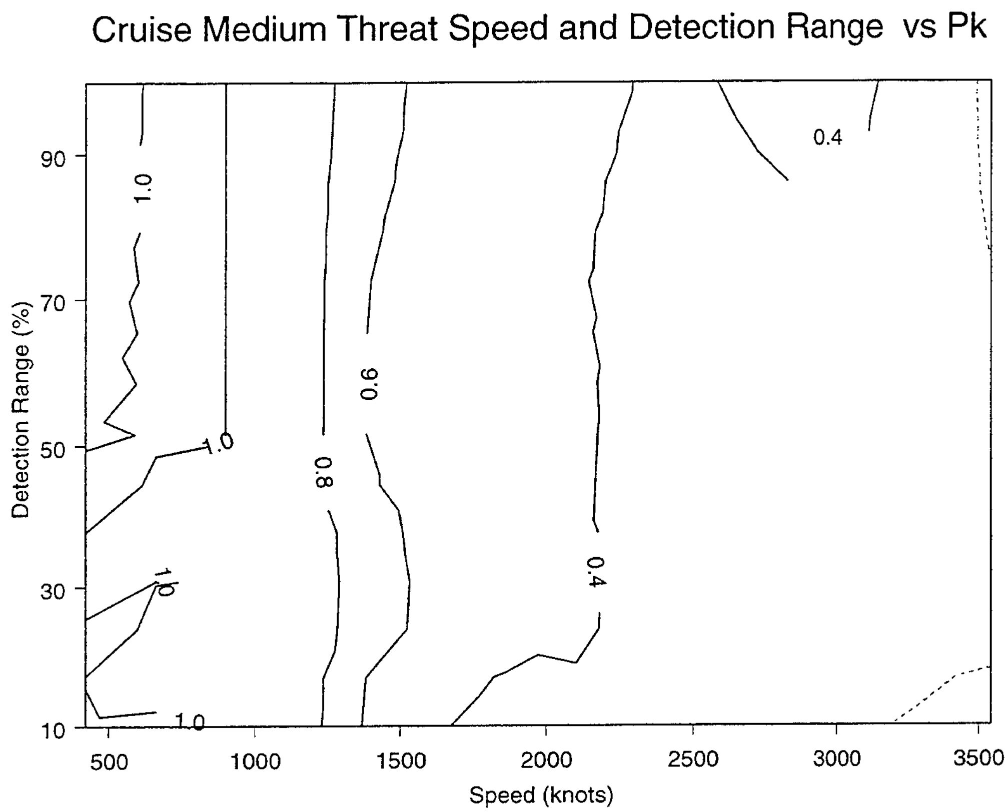

Figure 26. Contour Plot of the Medium Threat Scenario. Speed and Detection Range versus P_k. There is no Interaction Between Speed and Detection Range in the Medium Threat Scenario.

The high threat scenario, shown below in Figure 27, is very comparable to Figure 22 depicting detection range and speed interactions. The excursion runs are the only runs with a P_k of less than 1.0. A very low detection range, less than ten percent, and speeds from 1,610 – 1,933 knots give us LAM variants with an acceptable probability of survival as tested in this thesis. The contours are very close together because only three speeds are used in the excursion runs. These speeds are 966, 1,610, and 1,933 knots. The contours may extend further and straighter to the right if speeds greater than 1,933 knots are included in the excursion testing. Therefore, we infer that super and hypersonic LAM variants with speeds greater than 1,933 knots will also make it through the enemy air defenses.

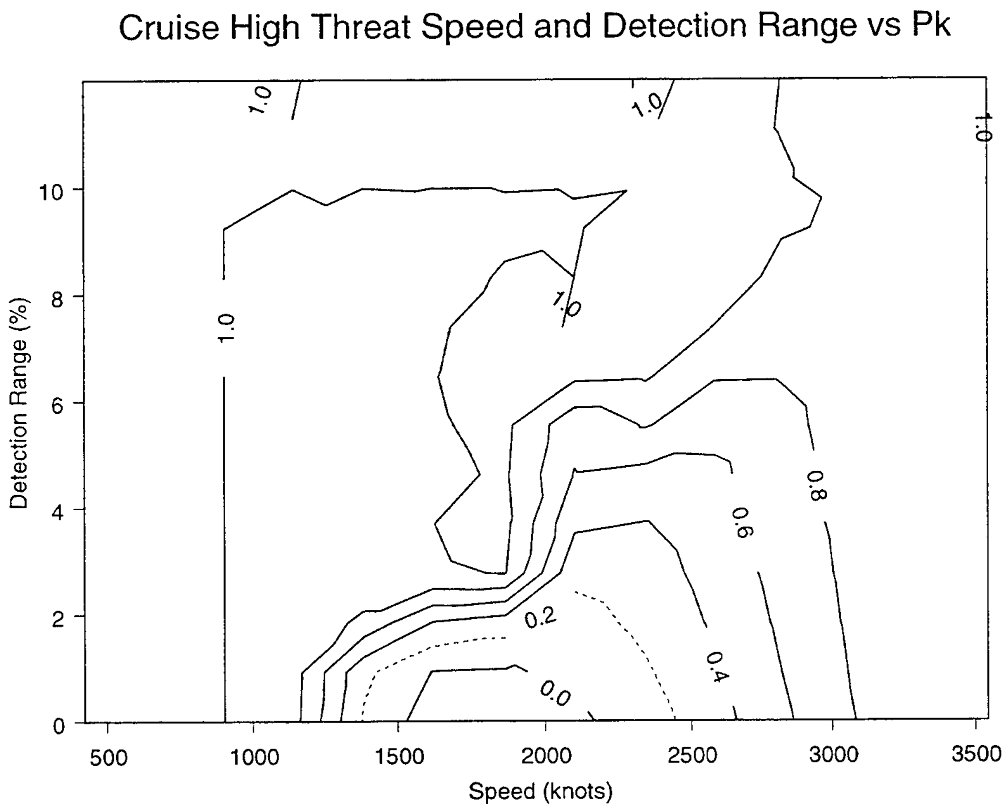

Figure 27. Contour Plot of the High Threat Scenario. Speed and Detection Range versus P_k for Detection Ranges ≤ 10%. There is no Interaction Between Speed and Detection Range in the High Threat Scenario.

b) Ballistic Missiles

Figure 28 below is a box plot of speed and detection range versus P_k for all the threat level scenarios. The box plot shows that every speed and detection range combination has a wide range of P_k values. The 10% detection range boxes indicate all of the P_k values are either 0 or 1.0. The 25% detection range boxes vary slightly for the different speeds in their medians and interquartile ranges. The 50 and 100% detection range boxes for the higher speed of 2,899 knots have lower medians and tighter IQRs. All the relationships regarding speed and detection range indicate that there is not an interaction taking place.

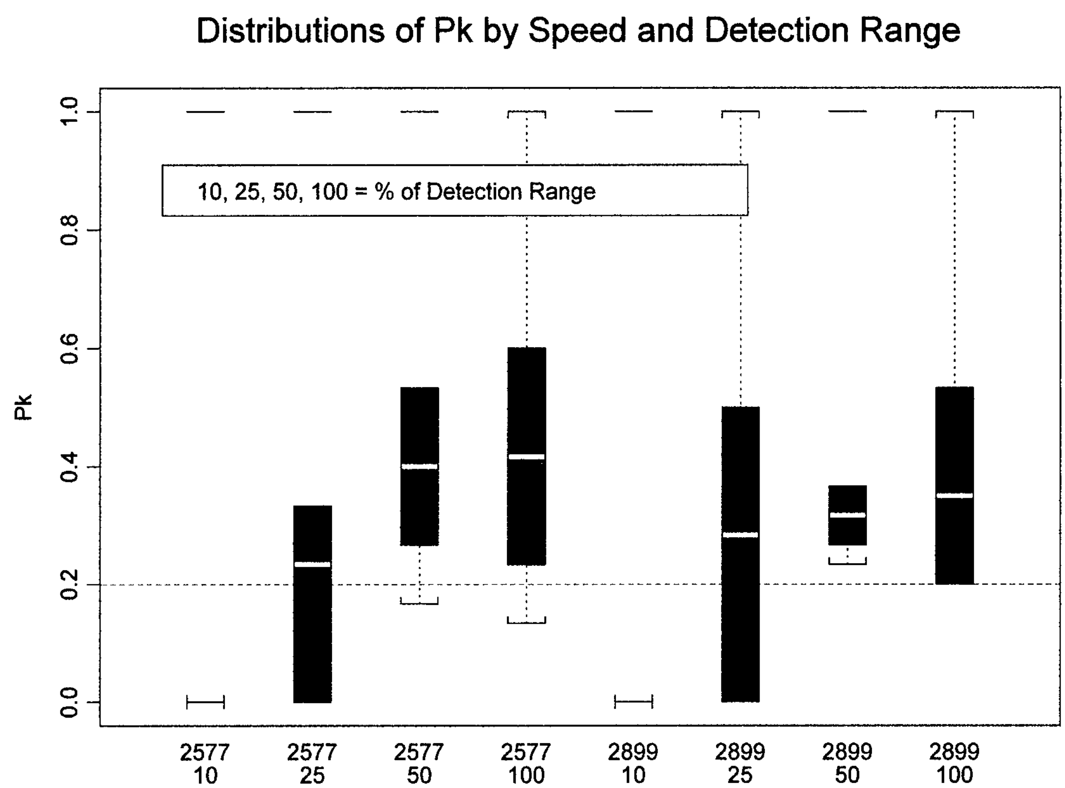

Figure 28. Box plot of Speed and Detection Range Versus P_k For All Threat Level Scenarios. There is no Interaction Between Speed and Detection Range.

Figure 29 allows a closer look at each scenario for a possible speed and detection range interaction. The box plots show each speed and detection range combination for each threat level scenario using Mach 4.0 and 4.5 as equivalent values for 2,577 and 2,899 knots respectively. All the speed and detection range combinations for the low threat scenario, except the 2,899 knot/50% detection range combination, have portions of their boxes less than or equal to P_k values of 0.2. The medium threat level scenario combinations with 10% detection range, like the low threat scenario, have P_k values of 0. The 50% detection range for both speeds and the 2,577-knot/100% detection range combination have unacceptable P_k values over 0.2. The high threat scenario combinations have P_k values greater than 0.2 with the exception of the 10% detection range combinations. The 10% detection range combinations have, however, a range of P_k values from 0 to 1.0, suggesting the third independent variable, trajectory, has an affect on these speed and detection range combinations, but speed is not interacting with detection range.

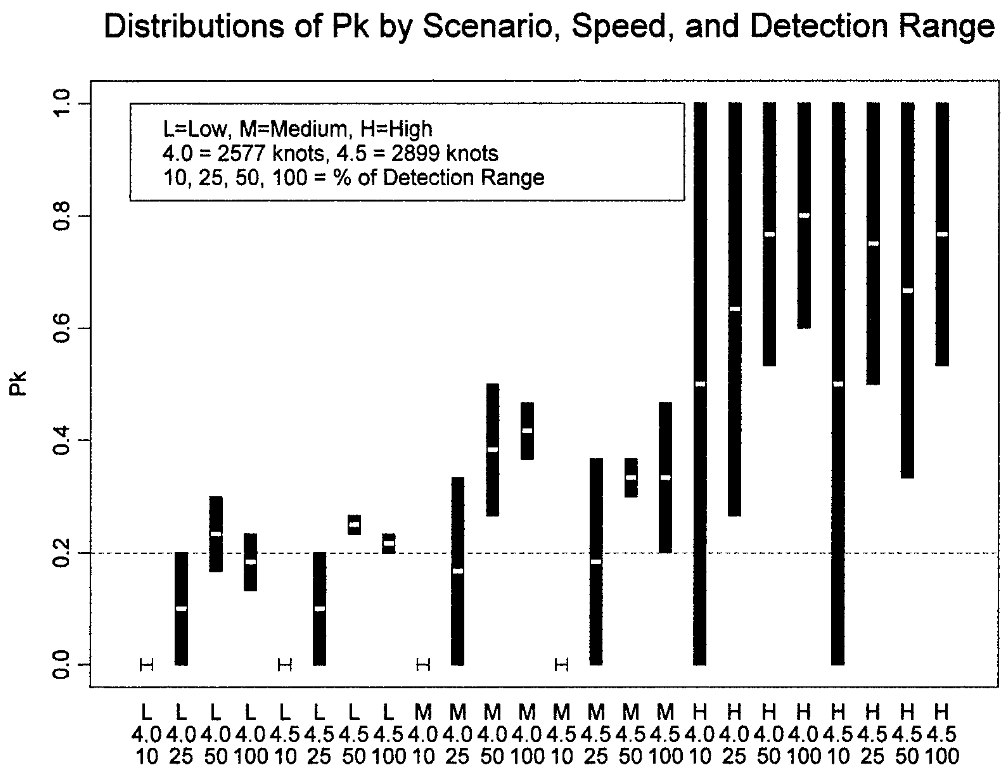

Figure 29. Box plot of Speed and Detection Range Versus P_k For Low, Medium, and High Threat Level Scenarios.

11. Two-Dimensional Summary

In the two-dimensional analysis of the independent variables above, there are several 2-way interactions that are significant. Over the range of values examined, the cruise missile LAM variants no interactions appear significant in the low threat scenario. The medium threat level scenario seems to have an altitude/speed interaction, which is verified by Figure 18. The only other interaction for the cruise missile LAMs is in the high threat scenario. Speed and detection range contain an interaction, but this is only seen in the excursion runs. The low and medium threat ballistic missile LAM scenarios contain a trajectory/detection range interaction. The high threat ballistic missile scenario contains a steady 1.0 P_k value for all depressed trajectory combinations, which will skew any interaction that may be present. More runs may help to improve predictability of the interactions of the independent variables in the high threat scenario.

IV. FITTING A MODEL

All of the one and two-dimensional factors have been examined in Chapter III. The smoothing splines fitted in Chapter III are non-parametric. The figures make it easy to see the trends in the data. In order to back up the non-parametric smoothing spline plots with statistics, parametric logistical regressions are run. A model is fitted for each scenario using the "stepAIC" function, which performs a stepwise logistical regression (Venables, 1999). Each scenario (low, medium, or high) and type (cruise or ballistic) combination of LAM is discussed below, except the high threat level scenario/cruise missile combination. The data for that combination is not revealing since all the P_k values are 1.0 (no survivability). Each of the models shows which of the independent variables are statistically significant. Each logistic regression begins with the full model and steps both backwards and forward using the Akaike Information Criterion, AIC, as the key measurement to a good model. Instead of using the coefficient of determination, R^2, we used AIC to stop the stepwise regression iterations. AIC is concerned with the total mean squared error (MSE) of the *n* fitted values for each subset regression model and is evaluated as:

$$AIC = [n * \log (SSE_P / n)] + 2*(n-p)$$

SSE_p is the error sum of squares for the fitted subset regression model with *p* parameters, that is, p-1 predictor variables and an intercept. This technique seeks to identify subsets of variables for which the AIC value is small. The sets of variables with small AIC values have a small MSE, and this makes the bias and variance of the regression model small. (MathSoft, Inc., 1999)

The t-values listed for each combination are significant in their values and sign. Only the end model is displayed below.

A. LOW THREAT SCENARIO

In the cruise missile scenario, altitude and speed are statistically significant for the low threat scenario. This is displayed below with the output of the logistic model in Table 10. The fitted logistic model is P_k ~ Altitude + Speed. The S-Plus output displays the coefficients on each of the independent variables in the model along with their corresponding standard error and t-value. The coefficient is the maximum likelihood estimator for the variable. A positive coefficient for altitude or speed indicates as they are increased, the P_k values decrease. The standard error is the error associated with estimating the coefficients and the t-value indicates how statistically significant, with greater absolute values indicating greater significance. If the variable is not significant, one would expect to see the absolute value of the t-value less than 2 about 95% of the time.

```
Coefficients:
                     Value    Std. Error    t value
(Intercept) -3.3706006748 0.09455973415 -35.64520
   Altitude  0.0006839912 0.00002417238  28.29640
      Speed  0.0012509299 0.00004570605  27.36903
```

Table 11. Logistic Model For the Low Threat Cruise Missile Scenario. As Altitude and Speed Increase, so does LAM Survivability.

In the ballistic missile scenario, trajectory, detection range, and the trajectory/detection range interaction are significant. This is shown statistically below with the output of the logistic model in Table 11. Because trajectory only has two factors, depressed or lofted, the negative coefficient indicates P_k values decrease if a depressed trajectory is used. Similarly, as the detection range decreases, so does P_k. The fitted logistic model is P_k ~ Trajectory + Detection Range + Trajectory:Detection Range. A semi-colon between two variables in a fitted logistic model indicates an interaction between these two variables.

```
Coefficients:
                    Value  Std. Error   t value
  (Intercept)  2.944126298 0.305417857  9.639667
   Trajectory -0.872450186 0.305417857 -2.856579
           DR -0.018646157 0.004091081 -4.557758
Trajectory:DR  0.009956635 0.004091081  2.433742
```

Table 12. Logistic Model For the Low Threat Ballistic Missile Scenario. Depressed Trajectory, Lower Detection Ranges and the Trajectory/Detection Range Interaction are Important Factors in the Model.

B. MEDIUM THREAT SCENARIO

In the medium threat cruise missile scenario, altitude, speed, detection range, the speed/detection range interaction, and the altitude/speed interaction are shown to be significant in the survivability of the LAM. This is outlined statistically below with the output of the logistic model in Table 12. The model is P_k ~ Altitude + Speed + Detection Range + Speed:Detection Range + Altitude:Detection Range.

Coefficients:

	Value	Std. Error	t value
(Intercept)	-4.708491e+000	2.129351e-001	-22.112333
Altitude	3.953237e-004	4.818964e-005	8.203500
Speed	1.542415e-003	9.496273e-005	16.242316
DR	3.388468e-003	2.761280e-003	1.227136
Speed:DR	-3.825659e-006	1.213947e-006	-3.151423
Altitude:Speed	3.705124e-008	2.353410e-008	1.574364

Table 13. Logistic Model For the Medium Threat Cruise Missile Scenario. Altitude and Speed are Important Factors in the Model.

In the ballistic missile scenario, trajectory, detection range, and the trajectory/detection range interaction are significant. This is identical to the low threat ballistic missile scenario and is shown below in Table 13. The fitted logistic model is P_k ~ Trajectory + Detection Range + Trajectory:Detection Range.

Coefficients:

	Value	Std. Error	t value
(Intercept)	2.63032268	0.263344301	9.988151
Trajectory	-1.12879041	0.263344301	-4.286367
DR	-0.02424414	0.003576827	-6.778115
Trajectory:DR	0.01422279	0.003576827	3.976370

Table 14. Logistic Model For the Medium Threat Ballistic Missile Scenario. Trajectory, Detection Range and the Trajectory/Detection Range Interaction are Important Factors in the Model.

C. HIGH THREAT SCENARIO

In the high threat cruise missile scenario, none of the independent variables are significant. In fact, all the P_k values are 1.0. In the ballistic missile scenario trajectory and detection range are statistically significant. This is displayed below in Table 14 with the output of the logistical regression model. The fitted logistic model is P_k ~ Trajectory + Detection Range.

```
Coefficients:
                  Value   Std. Error     t value
(Intercept) -5.1929405 12.945831526 -0.4011284
 Trajectory  6.9778226 12.944857168  0.5390421
         DR -0.0231681  0.004252713 -5.4478409
```

Table 15. Logistic Model For the High Threat Ballistic Missile Scenario. Trajectory, and Detection Range are Significant.

D. ALL THREAT LEVEL SCENARIOS

The stepwise logistical regression did not work for the aggregated cruise or ballistic missile scenarios. P_k values in the high threat scenarios make it impossible to determine a coefficient value that has a low standard error. To determine if the threat level is significant, a sign test is run. All the models are identical except for the threat level. If the threat level is insignificant, we would expect the calculated probability of kill, P_k, to be equally likely to be greater for each threat level. That is, with no threat difference, the number of combinations where the high threat level is greater than the medium, for example, should be binomially distributed with n = # of combinations, excluding ties, and p = 0.5. This hypothesis is checked with a sign test. The null hypothesis is H_0: p = .5 and the alternative hypothesis is H_a: p > .5 (Devore, 1995). Accepting the null hypothesis means that the threat level of the scenario does not matter. On the other hand, accepting the alternative hypothesis means the threat level of the scenario does matter. The p-value calculations are compared to the significance level of 0.05, and are displayed in Table 15 below.

	High vs Medium	Medium vs Low
Cruise Missile Scenarios	< 0.001	< 0.001
Ballistic Missile Scenarios	0.006	0.002

Table 16. P-value Results For High vs Medium and Medium vs Low Sign Tests to Determine if Threat Level is Highly Significant.

Based on the p-values in Table 15, we reject the null hypothesis in favor of the alternative. The sign test confirms that the threat level does matter and validates the design of the scenarios, which increasing in sophistication from low to high.

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V. CONCLUSIONS

Conclusions for each of the scenarios are presented separately, then for aggregated cruise and ballistic missiles. For all of the scenarios, we assume an alerted threat with a perfect state of readiness for enemy air defense sites. All the combinations that have a probability of survival of 80% (P_k values less than or equal to 0.2) are listed in Appendices C and D.

A. LOW THREAT SCENARIO

The low threat is vulnerable to both cruise and ballistic missile LAM variants. As altitude and speed variables increase, the probability the LAM is killed by an enemy air defense site, P_k, decreases in the cruise missile variants, supported by Figures 8 & 11 and Table 11. The most preferred ballistic missile variants in the low threat scenario have a depressed trajectory and a small detection range, as demonstrated in Figures 6 &16 and Table 12. As expected, many combinations of cruise and ballistic missiles penetrate the enemy air defenses in the low threat scenario.

B. MEDIUM THREAT SCENARIO

In the medium threat scenario the acceptable cruise missile LAM variants fly above 3,000 meters and at least 1,933 knots. The fitted logistical model in Table 13 supports the smoothing spline plot in Figures 8 & 11. As altitude and speed increase, the survivability of the LAM increases for the medium threat level cruise missiles. The ballistic missile variants, like the low threat scenario, are more survivable when the LAM variant has a depressed trajectory and a low detection range, as shown in Figures 6 & 16 and fitted in Table 14.

C. HIGH THREAT SCENARIO

The high threat scenario presents many problems for cruise and ballistic missile LAMs. A majority of the P_k values for both cruise and ballistic missiles are 1.0. The alerted, modern, integrated air defense is only penetrated by very stealthy cruise missiles with a detection range value of 1% and a speed of at least 1,933 knots, depressed trajectory ballistic missiles with a detection range value less than 10%, or lofted trajectory ballistic missiles.

D. ALL CRUISE MISSILES

In the low and medium threat scenario, higher altitudes and faster speeds increase the probability of survival for the LAM variants. In the high threat scenario, only excursion runs with an extremely low detection range of 1% make it through the air defenses.

E. ALL BALLISTIC MISSILES

The ballistic missile LAM variants are successful in the low and medium threat scenarios when the detection range is 50% or lower for depressed trajectories, or when a lofted trajectory is used. The high threat scenario is only defeated when the LAM has a lofted trajectory and a detection range of 10% or lower. Speed is not a factor in the ballistic missile LAMs examined.

F. SUMMARY

The high threat scenario proves to be the most difficult set of air defenses to penetrate. This is not surprising, but does indicate that a sophisticated missile must be used to achieve successful target destruction. The sign test confirms that the threat level of the scenario does make a difference in the success, or failure, of the LAM. The most survivable cruise missile LAM variants have an altitude of at least 4,000 meters, speed of at least 1,610 knots (Mach 2.3), and stealthy enough to limit the enemy air defense site detection range to 1% of its maximum range. Survivable ballistic missile LAM variants have a lofted trajectory, speed in the 2,577 knot (Mach 4.0) range, and stealthy enough to limit the enemy air defense site detection range to 10% of its maximum range.

APPENDIX A. CRUISE MISSILE RUN MATRIX

Cruise Missile Run Matrix

SUBSONIC CRUISE

Altitude (ft)	Altitude (m)	Speed (Mach)	(Knots)	Detection Range (%)
164	50	0.65	420	100
328	100	0.9	580	50
656	200			25
984	300			10
1,312	400			
1,640	500			
1,968	600			

SUPERSONIC CRUISE

Altitude (ft)	Altitude (m)	Speed (Mach)	(Knots)	Detection Range (%)
3,280	1,000	1.5	966	100
6,562	2,000	2.3	1610	50
9,842	3,000	3	1933	25
13,123	4,000	3.5	2255	10
16,404	5,000			
19,685	6,000			

HYPERSONIC CRUISE

Altitude (ft)	Altitude (m)	Speed (Mach)	(Knots)	Detection Range (%)
3,280	1,000	5	3221	100
6,562	2,000	5.5	3544	50
9,842	3,000			25
13,123	4,000			10
16,404	5,000			
19,685	6,000			

Table 17. Cruise Missile Run Matrix

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APPENDIX B. BALLISTIC MISSILE RUN MATRIX

Ballistic Missile Run Matrix

BALLISTIC (DEPRESSED TRAJECTORY)						
Scenario	Speed (Mach)	(Knots)	(M/s)	Apogee Altitude (ft)	(m)	Dive angle
Low	4	2577	1326	97,733	29,789	25
Low	4.5	2899	1492	105,396	32,125	25
Medium	4	2577	1326	82,634	25,187	23
Medium	4.5	2899	1492	85,971	26,204	23
High	4	2577	1326	108,365	33,030	20
High	4.5	2899	1492	108,592	33,099	20
BALLISTIC (LOFTED TRAJECTORY)						
Scenario	Speed (Mach)	(Knots)	(M/s)	Apogee Altitude (mi)	(m)	Dive angle
Low	4	2577	1326	388	624,385	83
Low	4.5	2899	1492	386	620,723	83
Medium	4	2577	1326	306	492,561	80
Medium	4.5	2899	1492	304	489,086	80
High	4	2577	1326	504	810,715	80
High	4.5	2899	1492	501	806,254	80

Table 18. Ballistic Missile Run Matrix

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APPENDIX C. SUCCESSFUL LAND ATTACK CRUISE MISSILES

Scenario	Altitude	Speed	DR	P_k
Low	1000	3221	25	0.166667
Low	1000	3544	10	0.166667
Low	1000	3544	25	0.2
Low	2000	2255	25	0.066667
Low	2000	3544	50	0.033333
Low	2000	3544	100	0.1
Low	2000	3544	10	0.1
Low	2000	3544	25	0.133333
Low	3000	966	50	0.2
Low	3000	1610	100	0.166667
Low	3000	1610	50	0.2
Low	3000	1933	100	0.1
Low	3000	1933	25	0.133333
Low	3000	1933	10	0.133333
Low	3000	2255	100	0.1
Low	3000	2255	50	0.166667
Low	3000	2255	10	0.166667
Low	3000	3221	10	0
Low	3000	3221	100	0.033333
Low	3000	3221	25	0.033333
Low	3000	3221	50	0.1
Low	3000	3544	50	0.033333
Low	3000	3544	25	0.033333
Low	3000	3544	100	0.1
Low	3000	3544	10	0.1
Low	4000	1610	25	0.1
Low	4000	1610	50	0.133333
Low	4000	1610	10	0.133333
Low	4000	1610	100	0.2
Low	4000	1933	25	0
Low	4000	1933	10	0
Low	4000	1933	100	0.066667
Low	4000	1933	50	0.1
Low	4000	2255	100	0
Low	4000	2255	50	0
Low	4000	2255	25	0
Low	4000	2255	10	0
Low	4000	3221	100	0
Low	4000	3221	10	0
Low	4000	3221	25	0.033333
Low	4000	3221	50	0.1
Low	4000	3544	100	0

Low	4000	3544	50	0
Low	4000	3544	25	0
Low	4000	3544	10	0
Low	5000	966	25	0.133333
Low	5000	966	100	0.166667
Low	5000	1610	10	0.066667
Low	5000	1610	25	0.133333
Low	5000	1933	50	0.033333
Low	5000	1933	100	0.1
Low	5000	1933	10	0.1
Low	5000	1933	25	0.166667
Low	5000	2255	25	0
Low	5000	2255	10	0
Low	5000	2255	50	0.066667
Low	5000	2255	100	0.1
Low	5000	3221	100	0
Low	5000	3221	50	0
Low	5000	3221	25	0
Low	5000	3221	10	0
Low	5000	3544	100	0
Low	5000	3544	50	0
Low	5000	3544	25	0
Low	5000	3544	10	0
Low	6000	966	10	0.1
Low	6000	966	25	0.133333
Low	6000	966	100	0.2
Low	6000	1610	100	0.133333
Low	6000	1610	50	0.133333
Low	6000	1933	100	0.066667
Low	6000	1933	50	0.066667
Low	6000	1933	10	0.1
Low	6000	1933	25	0.133333
Low	6000	2255	100	0.066667
Low	6000	2255	10	0.066667
Low	6000	2255	25	0.166667
Low	6000	2255	50	0.2
Low	6000	3221	100	0
Low	6000	3221	50	0
Low	6000	3221	25	0
Low	6000	3221	10	0
Low	6000	3544	100	0
Low	6000	3544	50	0
Low	6000	3544	25	0
Low	6000	3544	10	0
Medium	3000	3544	10	0.033333
Medium	3000	3544	25	0.2
Medium	4000	1610	10	0.2

Medium	4000	1933	10	0.066667
Medium	4000	1933	100	0.2
Medium	4000	2255	10	0.1
Medium	4000	3221	50	0
Medium	4000	3221	10	0.033333
Medium	4000	3221	100	0.1
Medium	4000	3221	25	0.133333
Medium	4000	3544	10	0
Medium	4000	3544	100	0.066667
Medium	4000	3544	50	0.066667
Medium	5000	1933	10	0
Medium	5000	1933	50	0.2
Medium	5000	2255	50	0.166667
Medium	5000	2255	10	0.166667
Medium	5000	3544	10	0
Medium	5000	3544	100	0.133333
Medium	5000	3544	25	0.133333
Medium	5000	3544	50	0.2
Medium	6000	1933	10	0.166667
Medium	6000	2255	50	0.133333
Medium	6000	2255	100	0.166667
Medium	6000	2255	25	0.166667
Medium	6000	2255	10	0.166667
Medium	6000	3221	50	0
Medium	6000	3221	25	0
Medium	6000	3221	10	0
Medium	6000	3221	100	0.033333
Medium	6000	3544	25	0
Medium	6000	3544	10	0
Medium	6000	3544	50	0.133333
Medium	6000	3544	100	0.166667
High	5000	1610	1	0
High	5000	1933	1	0

Table 19. Successful Land Attack Cruise Missiles For All Threat Level Scenarios.

APPENDIX D. SUCCESSFUL LAND ATTACK BALLISTIC MISSILES

Scenario	Trajectory	Speed	DR	P_k
Low	Depressed	2577	50	0.166667
Low	Depressed	2577	25	0
Low	Depressed	2577	10	0
Low	Depressed	2899	25	0
Low	Depressed	2899	10	0
Low	Lofted	2577	25	0.2
Low	Lofted	2577	100	0.133333
Low	Lofted	2577	10	0
Low	Lofted	2899	100	0.2
Low	Lofted	2899	25	0.2
Low	Lofted	2899	10	0
Medium	Depressed	2577	25	0
Medium	Depressed	2577	10	0
Medium	Depressed	2899	25	0
Medium	Depressed	2899	10	0
Medium	Lofted	2577	10	0
Medium	Lofted	2899	100	0.2
Medium	Lofted	2899	10	0
High	Lofted	2577	10	0
High	Lofted	2899	10	0

Table 20. Successful Land Attack Ballistic Missiles For All Threat Level Scenarios.

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APPENDIX E. COMPLETE CRUISE MISSILE DATA SET

Scenario	Altitude	Speed	DR	P_k
Low	50	420	100	1
Low	50	420	50	1
Low	50	420	25	1
Low	50	420	10	1
Low	50	580	100	0.8
Low	50	580	50	0.933333
Low	50	580	25	0.933333
Low	50	580	10	0.966667
Low	100	420	100	1
Low	100	420	50	1
Low	100	420	25	1
Low	100	420	10	0.966667
Low	100	580	100	0.933333
Low	100	580	50	1
Low	100	580	25	0.966667
Low	100	580	10	0.933333
Low	200	420	100	0.966667
Low	200	420	50	1
Low	200	420	25	1
Low	200	420	10	0.966667
Low	200	580	100	0.833333
Low	200	580	50	0.9
Low	200	580	25	0.966667
Low	200	580	10	0.933333
Low	300	420	100	1
Low	300	420	50	1
Low	300	420	25	0.966667
Low	300	420	10	1
Low	300	580	100	0.966667
Low	300	580	50	0.966667
Low	300	580	25	0.966667
Low	300	580	10	0.933333
Low	400	420	100	1
Low	400	420	50	1
Low	400	420	25	1
Low	400	420	10	0.966667
Low	400	580	100	0.9
Low	400	580	50	0.966667
Low	400	580	25	0.933333
Low	400	580	10	0.9
Low	500	420	100	1
Low	500	420	50	1
Low	500	420	25	1
Low	500	420	10	0.966667

Low	500	580	100	0.8
Low	500	580	50	0.866667
Low	500	580	25	0.933333
Low	500	580	10	0.933333
Low	600	420	100	0.966667
Low	600	420	50	1
Low	600	420	25	1
Low	600	420	10	1
Low	600	580	100	0.933333
Low	600	580	50	0.866667
Low	600	580	25	0.933333
Low	600	580	10	0.766667
Low	1000	966	100	0.7
Low	1000	966	50	0.666667
Low	1000	966	25	0.866667
Low	1000	966	10	0.733333
Low	1000	1610	100	0.633333
Low	1000	1610	50	0.6
Low	1000	1610	25	0.366667
Low	1000	1610	10	0.566667
Low	1000	1933	100	0.466667
Low	1000	1933	50	0.6
Low	1000	1933	25	0.5
Low	1000	1933	10	0.3
Low	1000	2255	100	0.466667
Low	1000	2255	50	0.466667
Low	1000	2255	25	0.333333
Low	1000	2255	10	0.433333
Low	1000	3221	100	0.333333
Low	1000	3221	50	0.266667
Low	1000	3221	25	0.166667
Low	1000	3221	10	0.3
Low	1000	3554	100	0.233333
Low	1000	3554	50	0.233333
Low	1000	3554	25	0.2
Low	1000	3554	10	0.166667
Low	2000	966	100	0.733333
Low	2000	966	50	0.666667
Low	2000	966	25	0.566667
Low	2000	966	10	0.566667
Low	2000	1610	100	0.3
Low	2000	1610	50	0.433333
Low	2000	1610	25	0.433333
Low	2000	1610	10	0.5
Low	2000	1933	100	0.466667
Low	2000	1933	50	0.466667
Low	2000	1933	25	0.566667
Low	2000	1933	10	0.4

Low	2000	2255	100	0.4
Low	2000	2255	50	0.233333
Low	2000	2255	25	0.066667
Low	2000	2255	10	0.3
Low	2000	3221	100	0.233333
Low	2000	3221	50	0.366667
Low	2000	3221	25	0.366667
Low	2000	3221	10	0.266667
Low	2000	3554	100	0.1
Low	2000	3554	50	0.033333
Low	2000	3554	25	0.133333
Low	2000	3554	10	0.1
Low	3000	966	100	0.433333
Low	3000	966	50	0.2
Low	3000	966	25	0.466667
Low	3000	966	10	0.4
Low	3000	1610	100	0.166667
Low	3000	1610	50	0.2
Low	3000	1610	25	0.333333
Low	3000	1610	10	0.366667
Low	3000	1933	100	0.1
Low	3000	1933	50	0.266667
Low	3000	1933	25	0.133333
Low	3000	1933	10	0.133333
Low	3000	2255	100	0.1
Low	3000	2255	50	0.166667
Low	3000	2255	25	0.233333
Low	3000	2255	10	0.166667
Low	3000	3221	100	0.033333
Low	3000	3221	50	0.1
Low	3000	3221	25	0.033333
Low	3000	3221	10	0
Low	3000	3554	100	0.1
Low	3000	3554	50	0.033333
Low	3000	3554	25	0.033333
Low	3000	3554	10	0.1
Low	4000	966	100	0.433333
Low	4000	966	50	0.4
Low	4000	966	25	0.3
Low	4000	966	10	0.266667
Low	4000	1610	100	0.2
Low	4000	1610	50	0.133333
Low	4000	1610	25	0.1
Low	4000	1610	10	0.133333
Low	4000	1933	100	0.066667
Low	4000	1933	50	0.1
Low	4000	1933	25	0
Low	4000	1933	10	0

Low	4000	2255	100	0
Low	4000	2255	50	0
Low	4000	2255	25	0
Low	4000	2255	10	0
Low	4000	3221	100	0
Low	4000	3221	50	0.1
Low	4000	3221	25	0.033333
Low	4000	3221	10	0
Low	4000	3554	100	0
Low	4000	3554	50	0
Low	4000	3554	25	0
Low	4000	3554	10	0
Low	5000	966	100	0.166667
Low	5000	966	50	0.233333
Low	5000	966	25	0.133333
Low	5000	966	10	0.233333
Low	5000	1610	100	0.233333
Low	5000	1610	50	0.266667
Low	5000	1610	25	0.133333
Low	5000	1610	10	0.066667
Low	5000	1933	100	0.1
Low	5000	1933	50	0.033333
Low	5000	1933	25	0.166667
Low	5000	1933	10	0.1
Low	5000	2255	100	0.1
Low	5000	2255	50	0.066667
Low	5000	2255	25	0
Low	5000	2255	10	0
Low	5000	3221	100	0
Low	5000	3221	50	0
Low	5000	3221	25	0
Low	5000	3221	10	0
Low	5000	3554	100	0
Low	5000	3554	50	0
Low	5000	3554	25	0
Low	5000	3554	10	0
Low	6000	966	100	0.2
Low	6000	966	50	0.333333
Low	6000	966	25	0.133333
Low	6000	966	10	0.1
Low	6000	1610	100	0.133333
Low	6000	1610	50	0.133333
Low	6000	1610	25	0.233333
Low	6000	1610	10	0.266667
Low	6000	1933	100	0.066667
Low	6000	1933	50	0.066667
Low	6000	1933	25	0.133333
Low	6000	1933	10	0.1

Low	6000	2255	100	0.066667
Low	6000	2255	50	0.2
Low	6000	2255	25	0.166667
Low	6000	2255	10	0.066667
Low	6000	3221	100	0
Low	6000	3221	50	0
Low	6000	3221	25	0
Low	6000	3221	10	0
Low	6000	3554	100	0
Low	6000	3554	50	0
Low	6000	3554	25	0
Low	6000	3554	10	0
Medium	50	420	100	1
Medium	50	420	50	1
Medium	50	420	25	1
Medium	50	420	10	1
Medium	50	580	100	1
Medium	50	580	50	1
Medium	50	580	25	1
Medium	50	580	10	1
Medium	100	420	100	1
Medium	100	420	50	1
Medium	100	420	25	1
Medium	100	420	10	1
Medium	100	580	100	1
Medium	100	580	50	1
Medium	100	580	25	1
Medium	100	580	10	1
Medium	200	420	100	1
Medium	200	420	50	1
Medium	200	420	25	1
Medium	200	420	10	1
Medium	200	580	100	1
Medium	200	580	50	1
Medium	200	580	25	1
Medium	200	580	10	1
Medium	300	420	100	0.933333
Medium	300	420	50	1
Medium	300	420	25	1
Medium	300	420	10	1
Medium	300	580	100	1
Medium	300	580	50	1
Medium	300	580	25	1
Medium	300	580	10	1
Medium	400	420	100	1
Medium	400	420	50	1
Medium	400	420	25	1
Medium	400	420	10	1

Medium	400	580	100	1
Medium	400	580	50	1
Medium	400	580	25	1
Medium	400	580	10	1
Medium	500	420	100	1
Medium	500	420	50	1
Medium	500	420	25	1
Medium	500	420	10	1
Medium	500	580	100	1
Medium	500	580	50	1
Medium	500	580	25	1
Medium	500	580	10	1
Medium	600	420	100	1
Medium	600	420	50	1
Medium	600	420	25	1
Medium	600	420	10	1
Medium	600	580	100	1
Medium	600	580	50	1
Medium	600	580	25	1
Medium	600	580	10	1
Medium	1000	966	100	1
Medium	1000	966	50	1
Medium	1000	966	25	1
Medium	1000	966	10	1
Medium	1000	1610	100	0.766667
Medium	1000	1610	50	0.666667
Medium	1000	1610	25	0.7
Medium	1000	1610	10	0.633333
Medium	1000	1933	100	0.666667
Medium	1000	1933	50	0.833333
Medium	1000	1933	25	0.733333
Medium	1000	1933	10	0.533333
Medium	1000	2255	100	0.533333
Medium	1000	2255	50	0.7
Medium	1000	2255	25	0.566667
Medium	1000	2255	10	0.466667
Medium	1000	3221	100	0.666667
Medium	1000	3221	50	0.3
Medium	1000	3221	25	0.333333
Medium	1000	3221	10	0.266667
Medium	1000	3544	100	0.266667
Medium	1000	3544	50	0.333333
Medium	1000	3544	25	0.5
Medium	1000	3544	10	0.5
Medium	2000	966	100	1
Medium	2000	966	50	1
Medium	2000	966	25	1
Medium	2000	966	10	1

Medium	2000	1610	100	0.833333
Medium	2000	1610	50	0.633333
Medium	2000	1610	25	0.866667
Medium	2000	1610	10	0.6
Medium	2000	1933	100	0.666667
Medium	2000	1933	50	0.633333
Medium	2000	1933	25	0.6
Medium	2000	1933	10	0.633333
Medium	2000	2255	100	0.633333
Medium	2000	2255	50	0.466667
Medium	2000	2255	25	0.6
Medium	2000	2255	10	0.666667
Medium	2000	3221	100	0.533333
Medium	2000	3221	50	0.533333
Medium	2000	3221	25	0.366667
Medium	2000	3221	10	0.333333
Medium	2000	3544	100	0.5
Medium	2000	3544	50	0.366667
Medium	2000	3544	25	0.4
Medium	2000	3544	10	0.333333
Medium	3000	966	100	1
Medium	3000	966	50	1
Medium	3000	966	25	1
Medium	3000	966	10	1
Medium	3000	1610	100	0.466667
Medium	3000	1610	50	0.5
Medium	3000	1610	25	0.633333
Medium	3000	1610	10	0.566667
Medium	3000	1933	100	0.433333
Medium	3000	1933	50	0.666667
Medium	3000	1933	25	0.633333
Medium	3000	1933	10	0.4
Medium	3000	2255	100	0.533333
Medium	3000	2255	50	0.4
Medium	3000	2255	25	0.366667
Medium	3000	2255	10	0.266667
Medium	3000	3221	100	0.433333
Medium	3000	3221	50	0.466667
Medium	3000	3221	25	0.3
Medium	3000	3221	10	0.333333
Medium	3000	3544	100	0.3
Medium	3000	3544	50	0.266667
Medium	3000	3544	25	0.2
Medium	3000	3544	10	0.033333
Medium	4000	966	100	1
Medium	4000	966	50	1
Medium	4000	966	25	1
Medium	4000	966	10	1

Medium	4000	1610	100	0.4
Medium	4000	1610	50	0.366667
Medium	4000	1610	25	0.466667
Medium	4000	1610	10	0.2
Medium	4000	1933	100	0.2
Medium	4000	1933	50	0.4
Medium	4000	1933	25	0.466667
Medium	4000	1933	10	0.066667
Medium	4000	2255	100	0.266667
Medium	4000	2255	50	0.3
Medium	4000	2255	25	0.266667
Medium	4000	2255	10	0.1
Medium	4000	3221	100	0.1
Medium	4000	3221	50	0
Medium	4000	3221	25	0.133333
Medium	4000	3221	10	0.033333
Medium	4000	3544	100	0.066667
Medium	4000	3544	50	0.066667
Medium	4000	3544	25	0.233333
Medium	4000	3544	10	0
Medium	5000	966	100	1
Medium	5000	966	50	1
Medium	5000	966	25	1
Medium	5000	966	10	1
Medium	5000	1610	100	0.5
Medium	5000	1610	50	0.4
Medium	5000	1610	25	0.266667
Medium	5000	1610	10	0.3
Medium	5000	1933	100	0.3
Medium	5000	1933	50	0.2
Medium	5000	1933	25	0.3
Medium	5000	1933	10	0
Medium	5000	2255	100	0.333333
Medium	5000	2255	50	0.166667
Medium	5000	2255	25	0.266667
Medium	5000	2255	10	0.166667
Medium	5000	3221	100	0.5
Medium	5000	3221	50	0.433333
Medium	5000	3221	25	0.3
Medium	5000	3221	10	0.233333
Medium	5000	3544	100	0.133333
Medium	5000	3544	50	0.2
Medium	5000	3544	25	0.133333
Medium	5000	3544	10	0
Medium	6000	966	100	1
Medium	6000	966	50	1
Medium	6000	966	25	1
Medium	6000	966	10	1

Medium	6000	1610	100	0.3
Medium	6000	1610	50	0.4
Medium	6000	1610	25	0.3
Medium	6000	1610	10	0.266667
Medium	6000	1933	100	0.266667
Medium	6000	1933	50	0.266667
Medium	6000	1933	25	0.333333
Medium	6000	1933	10	0.166667
Medium	6000	2255	100	0.166667
Medium	6000	2255	50	0.133333
Medium	6000	2255	25	0.166667
Medium	6000	2255	10	0.166667
Medium	6000	3221	100	0.033333
Medium	6000	3221	50	0
Medium	6000	3221	25	0
Medium	6000	3221	10	0
Medium	6000	3544	100	0.166667
Medium	6000	3544	50	0.133333
Medium	6000	3544	25	0
Medium	6000	3544	10	0
High	50	420	100	1
High	50	420	50	1
High	50	420	25	1
High	50	420	10	1
High	50	580	100	1
High	50	580	50	1
High	50	580	25	1
High	50	580	10	1
High	100	420	100	1
High	100	420	50	1
High	100	420	25	1
High	100	420	10	1
High	100	580	100	1
High	100	580	50	1
High	100	580	25	1
High	100	580	10	1
High	200	420	100	1
High	200	420	50	1
High	200	420	25	1
High	200	420	10	1
High	200	580	100	1
High	200	580	50	1
High	200	580	25	1
High	200	580	10	1
High	300	420	100	1
High	300	420	50	1
High	300	420	25	1
High	300	420	10	1

High	300	580	100	1
High	300	580	50	1
High	300	580	25	1
High	300	580	10	1
High	400	420	100	1
High	400	420	50	1
High	400	420	25	1
High	400	420	10	1
High	400	580	100	1
High	400	580	50	1
High	400	580	25	1
High	400	580	10	1
High	500	420	100	1
High	500	420	50	1
High	500	420	25	1
High	500	420	10	1
High	500	580	100	1
High	500	580	50	1
High	500	580	25	1
High	500	580	10	1
High	600	420	100	1
High	600	420	50	1
High	600	420	25	1
High	600	420	10	1
High	600	580	100	1
High	600	580	50	1
High	600	580	25	1
High	600	580	10	1
High	1000	966	100	1
High	1000	966	50	1
High	1000	966	25	1
High	1000	966	10	1
High	1000	1610	100	1
High	1000	1610	50	1
High	1000	1610	25	1
High	1000	1610	10	1
High	1000	1933	100	1
High	1000	1933	50	1
High	1000	1933	25	1
High	1000	1933	10	1
High	1000	2255	100	1
High	1000	2255	50	1
High	1000	2255	25	1
High	1000	2255	10	1
High	1000	3221	100	1
High	1000	3221	50	1
High	1000	3221	25	1
High	1000	3221	10	0.966667

High	1000	3544	100	1
High	1000	3544	50	1
High	1000	3544	25	1
High	1000	3544	10	1
High	2000	966	100	1
High	2000	966	50	1
High	2000	966	25	1
High	2000	966	10	1
High	2000	1610	100	1
High	2000	1610	50	1
High	2000	1610	25	1
High	2000	1610	10	1
High	2000	1933	100	1
High	2000	1933	50	1
High	2000	1933	25	1
High	2000	1933	10	1
High	2000	2255	100	1
High	2000	2255	50	1
High	2000	2255	25	1
High	2000	2255	10	1
High	2000	3221	100	1
High	2000	3221	50	1
High	2000	3221	25	1
High	2000	3221	10	1
High	2000	3544	100	1
High	2000	3544	50	1
High	2000	3544	25	1
High	2000	3544	10	1
High	3000	966	100	1
High	3000	966	50	1
High	3000	966	25	1
High	3000	966	10	1
High	3000	1610	100	1
High	3000	1610	50	1
High	3000	1610	25	1
High	3000	1610	10	1
High	3000	1933	100	1
High	3000	1933	50	1
High	3000	1933	25	1
High	3000	1933	10	1
High	3000	2255	100	1
High	3000	2255	50	1
High	3000	2255	25	1
High	3000	2255	10	1
High	3000	3221	100	1
High	3000	3221	50	1
High	3000	3221	25	1
High	3000	3221	10	1

High	3000	3544	100	1
High	3000	3544	50	1
High	3000	3544	25	1
High	3000	3544	10	1
High	4000	966	100	1
High	4000	966	50	1
High	4000	966	25	1
High	4000	966	10	1
High	4000	1610	100	1
High	4000	1610	50	1
High	4000	1610	25	1
High	4000	1610	10	1
High	4000	1933	100	1
High	4000	1933	50	1
High	4000	1933	25	1
High	4000	1933	10	1
High	4000	2255	100	1
High	4000	2255	50	1
High	4000	2255	25	1
High	4000	2255	10	1
High	4000	3221	100	1
High	4000	3221	50	1
High	4000	3221	25	1
High	4000	3221	10	1
High	4000	3544	100	1
High	4000	3544	50	1
High	4000	3544	25	1
High	4000	3544	10	1
High	5000	966	100	1
High	5000	966	50	1
High	5000	966	25	1
High	5000	966	10	1
High	5000	966	1	1
High	5000	1610	100	1
High	5000	1610	50	1
High	5000	1610	25	1
High	5000	1610	10	1
High	5000	1610	5	0.966667
High	5000	1610	3	1
High	5000	1610	1	0
High	5000	1933	100	1
High	5000	1933	50	1
High	5000	1933	25	1
High	5000	1933	10	1
High	5000	1933	5	1
High	5000	1933	3	1
High	5000	1933	1	0
High	5000	2255	100	1

High	5000	2255	50	1
High	5000	2255	25	1
High	5000	2255	10	1
High	5000	3221	100	1
High	5000	3221	50	1
High	5000	3221	25	1
High	5000	3221	10	1
High	5000	3544	100	1
High	5000	3544	50	1
High	5000	3544	25	1
High	5000	3544	10	1
High	6000	966	100	1
High	6000	966	50	1
High	6000	966	25	1
High	6000	966	10	1
High	6000	1610	100	1
High	6000	1610	50	1
High	6000	1610	25	1
High	6000	1610	10	1
High	6000	1933	100	1
High	6000	1933	50	1
High	6000	1933	25	1
High	6000	1933	10	1
High	6000	2255	100	1
High	6000	2255	50	1
High	6000	2255	25	1
High	6000	2255	10	1
High	6000	3221	100	1
High	6000	3221	50	1
High	6000	3221	25	1
High	6000	3221	10	1
High	6000	3544	100	1
High	6000	3544	50	1
High	6000	3544	25	1
High	6000	3544	10	1

Table 21. Complete Cruise Missile Data Set For All Threat Level Scenarios.

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APPENDIX F. COMPLETE BALLISTIC MISSILE DATA SET

Scenario	Trajectory	Speed	DR	P_k
Low	Depressed	2577	100	0.233333
Low	Depressed	2577	50	0.166667
Low	Depressed	2577	25	0
Low	Depressed	2577	10	0
Low	Depressed	2899	100	0.233333
Low	Depressed	2899	50	0.233333
Low	Depressed	2899	25	0
Low	Depressed	2899	10	0
Low	Lofted	2577	100	0.133333
Low	Lofted	2577	50	0.3
Low	Lofted	2577	25	0.2
Low	Lofted	2577	10	0
Low	Lofted	2899	100	0.2
Low	Lofted	2899	50	0.266667
Low	Lofted	2899	25	0.2
Low	Lofted	2899	10	0

Table 22. Data Set For the Low Threat Ballistic Missile Scenario.

Scenario	Trajectory	Speed	DR	P_k
Medium	Depressed	2577	100	0.466667
Medium	Depressed	2577	50	0.266667
Medium	Depressed	2577	25	0
Medium	Depressed	2577	10	0
Medium	Depressed	2899	100	0.466667
Medium	Depressed	2899	50	0.3
Medium	Depressed	2899	25	0
Medium	Depressed	2899	10	0
Medium	Lofted	2577	100	0.366667
Medium	Lofted	2577	50	0.5
Medium	Lofted	2577	25	0.333333
Medium	Lofted	2577	10	0
Medium	Lofted	2899	100	0.2
Medium	Lofted	2899	50	0.366667
Medium	Lofted	2899	25	0.366667
Medium	Lofted	2899	10	0

Table 23. Data Set For the Medium Threat Ballistic Missile Scenario.

Scenario	Trajectory	Speed	DR	P_k
High	Depressed	2577	100	1
High	Depressed	2577	50	1
High	Depressed	2577	25	1
High	Depressed	2577	10	1
High	Depressed	2899	100	1
High	Depressed	2899	50	1
High	Depressed	2899	25	1
High	Depressed	2899	10	1
High	Lofted	2577	100	0.6
High	Lofted	2577	50	0.533333
High	Lofted	2577	25	0.266667
High	Lofted	2577	10	0
High	Lofted	2899	100	0.533333
High	Lofted	2899	50	0.333333
High	Lofted	2899	25	0.5
High	Lofted	2899	10	0

Table 24. Data Set For the High Threat Ballistic Missile Scenario.

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